SCIENCE AND INDUSTRY

VOLUME L NUMBER 8

DEC 30 1942
LOS ANGELES PUBLIC LIBRARY

# THE JOURNAL of GEOLOGY

A SEMI-QUARTERLY

REFERENCE
DO NOT LOAN

EDITED BY
ROLLIN T. CHAMBERLIN

With the Active Collaboration of

EDSON S. BASTIN, Economic Geology
NORMAN L. BOWEN, Petrology
J HARLEN BRETZ, Geomorphology
CAREY CRONEIS, Invertebrate Paleontology
D. JEROME FISHER, Mineralogy
FRANCIS J. PETTIJOHN, Sedimentology
ALFRED S. ROMER, Vertebrate Paleontology

ASSOCIATE EDITORS

H. ALBERT BROUWER, The Netherlands
GERARD DeGEER, Sweden
ALBRECHT PENCK, Germany
FRANK D. ADAMS, McGill University
WALLACE W. ATWOOD, Clark University
ARTHUR L. DAY, Carnegie Institution
WILLIAM H. EMMONS, University of Minnesota
WILLIAM H. HOBBS, University of Michigan
CHARLES K. LEITH, University of Wisconsin
ELWOOD S. MOORE, University of Toronto
JOHN B. REESIDE, Jr., U.S. Geological Survey
BAILEY WILLIS, Stanford University

## NOVEMBER-DECEMBER 1942

EDOPS, A PRIMITIVE RHACHITOMOUS AMPHIBIAN FROM THE TEXAS RED BEDS
ALFRED S. ROMER AND ROBERT V. WITTER 925

STRUCTURE OF LITTLE NORTH MOUNTAIN OF THE NORTH-CENTRAL APPALACHIANS - - - - - - - - - - - - - - - - ALBERT W. GILES 961

CONTRIBUTIONS OF BOTANICAL SCIENCE TO THE KNOWLEDGE OF POSTGLACIAL CLIMATES - - - - - - - - - - - - - - - - WILLIAM S. COOPER 981

DISCUSSION: WIND WORK ACCOMPANYING AND FOLLOWING GLACIATION
LINCOLN R. THIESMEYER AND RALPH E. DIGMAN 995

NOTE BY FRANK LEVERETT - - - - - - - - - - - - - - - - - 1001

REVIEWS

*Dana's Manual of Mineralogy*, CORNELIUS S. HURLBUT, JR. (rev.) (D. J. F.) - - - - - - 1003

*Possible Future Oil Provinces of the United States and Canada*, A. I. LEVORSEN (ed.) (W. C. Krumbein) - - - - - - - - - - - - - - - - - - - - - - - - 1004

*Coal Paleobotany*, REINHARDT THIESSEN AND GEORGE C. SPRUNK (Ernest P. Du Bois) - - - 1005

*Small Foraminifera from the Late Tertiary of the Nederlands, East Indies*, L. W. LEROY (C. W. Sternberg) - - - - - - - - - - - - - - - - - - - - - - - - - 1006

*Introduction to Physical Geology*, W. J. MILLER (Ernest P. Du Bois) - - - - - - - - - 1006

*A Middle Eocene Flora from the Central Sierra Nevada*, HARRY D. MACGINITIE (Ernest P. Du Bois) 1007

INDEX - - - - - - - - - - - - - - - - - - - - - - - - - - 1009

THE UNIVERSITY OF CHICAGO PRESS
CHICAGO, ILLINOIS, U.S.A.

November-December 1942 Vol. L, No. 8

# THE JOURNAL OF GEOLOGY

EDITED BY
ROLLIN T. CHAMBERLIN

With the Active Collaboration of

EDSON S. BASTIN
Economic Geology

CAREY CRONEIS
Invertebrate Paleontology

NORMAN L. BOWEN
Petrology

D. JEROME FISHER
Mineralogy

J HARLEN BRETZ
Geomorphology

FRANCIS J. PETTIJOHN
Sedimentology

ALFRED S. ROMER
Vertebrate Paleontology

**The Journal of Geology** is published by the University of Chicago at the University of Chicago Press, 5750 Ellis Avenue, Chicago, Illinois, semi-quarterly, on or about the following dates: February 1, March 15, May 1, June 15, August 1, September 15, November 1, December 14. ¶ The subscription price is $6.00 per year, the price of single copies is $1.00. Orders for service of less than a full year will be charged at the single-copy rate. ¶ Postage is prepaid by the publishers on all orders from the United States and its possessions, Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Guatemala, Haiti, Republic of Honduras, Mexico, Morocco (Spanish Zone), Nicaragua, Panama, Paraguay, Peru, Rio de Oro, El Salvador, Spain (including Balearic Islands, Canary Islands, and the Spanish Offices in Northern Africa; Andorra), Spanish Guinea, Uruguay, and Venezuela. ¶ Postage is charged extra as follows: for Canada and Newfoundland, 32 cents on annual subscriptions (total $6.32); on single copies 4 cents (total $1.04); for all other countries in the Postal Union 80 cents on annual subscriptions (total $6.80), on single copies 10 cents (total $1.10). ¶ Patrons are requested to make all remittances payable to The University of Chicago Press in United States currency or its equivalent by postal or express money orders or bank drafts.

**The following** are authorized agents:

For the British Empire, except North America, India, and Australasia: The Cambridge University Press, Bentley House, 200 Euston Road, London, N.W. 1. Prices of yearly subscriptions and of single copies may be had on application.

**Claims for missing numbers** should be made within the month following the regular month of publication. The publishers expect to supply missing numbers free only when losses have been sustained in transit, and when the reserve stock will permit.

**Business correspondence** should be addressed to The University of Chicago Press, Chicago, Ill.

**Communications for the editors** and manuscripts should be addressed to the Editor of THE JOURNAL OF GEOLOGY, The University of Chicago, Chicago, Ill.

**Contributors are requested** to write scientific and proper names with particular care and in citations to follow the form shown in the pages of the Journal.

**Because of the high cost of printing**, this Journal has found it necessary to adopt the following rules. ¶ 1. The cost of illustrative material, in excess of $1.50 per page for the article, beyond the cost of type which would have occupied the same space, shall be borne by the author. ¶ 2. The cost of excessive alterations (i.e., changes from the original manuscript) made by the author will be charged to him. ¶ 3. For the present the Journal will supply free 50 reprints (without covers) of each article. Additional reprints must be ordered in advance of publication; rates will be furnished on request.

**The articles in this Journal** are indexed in the *International Index to Periodicals*, New York, N.Y.

**Applications for permission to quote** from this Journal should be addressed to The University of Chicago Press, and will be freely granted.

Entered as second-class matter March 20, 1893, at the Post-office at Chicago, Ill., under the Act of March 3, 1879.

Acceptance for mailing at special rate of postage provided for in United States Postal Act of October 3, 1917, Section 1103, amended February 28, 1925, authorized July 15, 1918.

[PRINTED IN U.S.A.]

VOLUME L NUMBER 8

THE
JOURNAL OF GEOLOGY

*November-December 1942*

# EDOPS, A PRIMITIVE RHACHITOMOUS AMPHIBIAN FROM THE TEXAS RED BEDS

ALFRED S. ROMER
Harvard University

ROBERT V. WITTER
Harvard University

ABSTRACT

A description is given of the skull and such postcranial material as is known of *Edops craigi*, a large labyrinthodont amphibian from the Wichita Permo-Carboniferous beds of Texas. The structure of the *Edops* skull shows this form to be a very primitive member of the Rhachitomi, approaching the embolomerous stage in many structural features.

## INTRODUCTION

It was long assumed that the only large amphibian present in the Permo-Carboniferous deposits of the Texas region was the familiar *Eryops*. Some years ago, however, the senior author, while exploring horizons lower than those usually visited by collectors found remains of a rhachitomous amphibian of large size. While exceedingly fragmentary, they obviously represented a form markedly different from *Eryops;* this was described, in preliminary fashion, as *Edops craigi*.[1]

The finding of further remains of *Edops* was made a special object of an expedition to these beds by the authors in 1936. By good fortune a specimen was discovered which included a nearly complete

[1] A. S. Romer, "Studies on American Permo-Carboniferous Tetrapods," *Problems of Paleontology*, Vol. I (1936), pp. 85–93.

skull, which forms the basis for much of the description given below. In the course of other recent collecting trips by the Museum of Comparative Zoölogy still other remains have been found. The materials now available include the following specimens:

*M.C.Z. 1378.*—Most of skull and jaws and a few postcranial fragments. Remains mixed with those of an *Eryops* of smaller size. Terrapin School, Archer County, Texas; Moran Formation. Collected by R. V. Witter. Our skull descriptions are based on this specimen.

*M.C.Z. 1235.*—Fragmentary remains of skull and jaw and a few postcranial fragments; including valuable jaw and brain-case material. Padgett, Young County; Moran Formation. Collected by L. I. Price and T. E. White.

*M.C.Z. 1453.*—A large quantity of fragmentary material, collected by various expeditions. Head of Cottonwood Creek, Archer County; Moran Formation.

*M.C.Z. 1782.*—A number of fragments collected by various expeditions. Padgett.

*M.C.Z. 1781.*—Humerus. Terrapin School. Collected by L. I. Price.

*M.C.Z. 1770.*—Partial skeleton of a small individual. Two and one-half miles east of Antelope, Jack County; Pueblo Formation. Collected by L. I. Price and A. S. Romer.

*M.C.Z. 1769.*—A few remains in a difficult matrix. Same data as for *M.C.Z. 1770.*

Preparation and study of these materials now enables us to give a moderately adequate account of the cranial osteology of *Edops* and some data on the postcranial skeleton. Despite the lack of complete associated material, the identification of fragmentary pieces and isolated elements has not proved difficult in most cases. The nearly complete skull of No. 1378 has rendered easy the recognition of cranial materials. The identification of isolated postcranial elements is somewhat more hazardous. However, except for *Eryops*, all remains of large amphibians in the horizons concerned include, for each element, only a single structural type. In a number of cases the elements are definitely comparable to those of *Edops* specimens Nos. 1235 and 1770. It is therefore reasonable to assume that this material in general pertains to this genus.

The stratigraphic occurrence of *Edops* is not without interest.[2] Most Texas red-beds collections have been obtained from a series of formations which include the Admiral, Belle Plains, Clyde and Arroyo (in ascending order). In these deposits *Eryops* is exceedingly common, but no trace of *Edops* has ever been found. Below the Admiral are three other formations—Putnam, Moran, and Pueblo, in descending order—which have recently been explored by the Museum of Comparative Zoölogy. (Below this there is a rapid change to marine strata without fossil vertebrates.) In these formations fossils are relatively rare but of interest in that the fauna is rather different from that in higher formations, although a number of familiar types, such as *Eryops*, are present. It is in these deposits that *Edops* occurs. It has not been found thus far in the Putnam. In the Moran, however, it appears to be a common element in the fauna; its remains constitute a large proportion of materials collected from this horizon. In the Pueblo, fossil finds are extremely limited; but, even so, *Edops* is definitely identified from this formation. It seems clear that *Edops* is a component of an early faunal radiation of rhachitomous amphibians and is essentially a Carboniferous rather than a Permian type.

## GENERAL DESCRIPTION

### SKULL

*General structure.*—The description and figures are essentially based on No. 1378. This specimen was found broken into numerous fragments. Certain portions were not recovered, but the entire roof structure is determinable except for the tip of the snout; and even here the contour can be inferred readily from that of the lower jaw. The palate is fragmentary; the brain case is nearly perfectly preserved.

Although crushing has flattened the cheek region and introduced some uncertainty in measurements there, the general proportions can be readily determined. The skull is remarkable for its size. The length, as restored, is 63 cm. to a line through the quadrates and 51

[2] Romer, "Early History of Texas Red Beds Vertebrates," *Bull. Geol. Soc. Amer.*, Vol. XLVI (1935), pp. 1597–1658. In current geological discussions of Texas stratigraphy various suggestions of revision of nomenclature have been advocated; these, however, do not alter the essential picture.

cm. to the occipital condyle; the greatest width as preserved is 48 cm. and was in life presumably about 45 cm. The size is greater than that of any other pre-Triassic amphibian familiar to us. In the red beds, *Eryops* is the nearest competitor; but, of a series of skulls measured by H. J. Sawin,[3] the largest measures only 52.5 cm. in greatest length and most are markedly smaller. The skull illustrated is probably close to maximum size; the more fragmentary remains of other skulls in general indicate individuals of smaller proportions.

The proportions are not far from those of *Eryops* and approximate those which Watson believes characteristic of generalized labyrinthodonts. The width is about 70 per cent of the total length, as compared with about 75 per cent in *Eryops*, 80 per cent in *Palaeogyrinus*, about 75 per cent in *Pholidogaster*, etc. The slightly lower figure is to be correlated, perhaps, with the relatively long posterior extension of the suspensorial region. In *Edops* the distance to the tip of the quadrate exceeds that to the condyles by about 10 per cent. In *Eryops* the suspensorium is shorter posteriorly; and still further shortening occurs in more "advanced" rhachitomous forms and stereospondyls; D. M. S. Watson[4] has discussed the functional significance of this shortening. On the other hand, the posterior extension of the *Edops* suspensorium is rather less than that seen in a number of Carboniferous forms, presumably still more primitive in nature.

In *Edops* the distance from snout to center of orbits is about 60 per cent of the length of the skull roof; the eyes are thus somewhat posteriorly placed, and the relative position is approximately that seen in *Eryops*, *Actinodon*, *Sclerocephalus*, *Palaeogyrinus*, *Pholidogaster*, *etc.* This condition seems reasonably interpretable as a primitive one for labyrinthodonts in general.

Because of post mortem crushing, the depth of the skull is difficult to determine. It seems probable that the skull is somewhat deeper than in *Eryops* and hence somewhat closer to primitive conditions.

[3] "The Cranial Anatomy of *Eryops megacephalus*," *Bull. Mus. Comp. Zoöl.*, Vol. LXXXVIII, No. 5 (1941), p. 410.

[4] "The Structure, Evolution and Origin of the Amphibia—the 'Orders' Rachitomi and Stereospondyli," *Phil. Trans. Roy. Soc. London*, Ser. B, Vol. CCIX (1919), p. 57.

*Roofing bones.*—To depict the skull roof (Fig. 1) we have chosen a photograph of a cast rather than the specimen itself, since the coloration of the original does not lend itself well to photography. The course of the sutures is indicated by India-ink lines. The skull was so cracked and checked in various areas that determination of sutures was by no means an easy task. While we have confidence that the

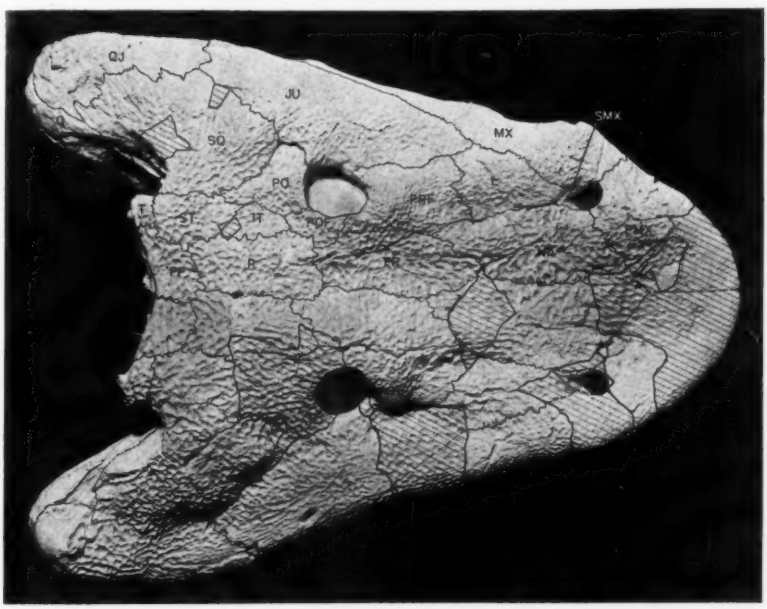


FIG. 1.—Dorsal view of skull. ×¾. Photograph of cast. Restored areas are indicated

sutures indicated are for the most part accurate, it is quite possible that certain details may be erroneous. Most of the sutures have been confirmed by study of the lower surface.

In general the sculpture is of the common labyrinthodont type. It is rather coarse, with areas of finer sculpturing occurring along the dental margins and along a band from orbit to the lateral margins of the nares. There are no indications of lateral-line canals. The roof is somewhat concave along the mid-line, with high ridges along the upper margins of the orbits, where the bone is much thickened;

there is an especially thick and elevated area in the prefrontal region, lateral to which is a marked depression near the prefrontal-jugal suture. Ridges extend anteriorly from the prefrontal thickenings toward the snout and diverge anterolaterally along the lacrimals. Prominent swellings are present on the maxilla external to the nares. These swollen areas are the most massive pieces of bone in the skeleton and have been found isolated on various occasions.[5]

The general region of the tabulars is thickened and swollen, and from the posterior margins of these bones project rounded processes comparable to those seen in loxommids. The otic notch is typically developed, with a well-rounded anterior margin, and, in contrast with presumed primitive conditions, there is a firm union of cheek and table anterior to the notch.

The external nares open as much posteriorly as directly dorsally, the openings being at the anterior end of grooves developed in the septomaxillae. The naris is in great measure bounded by the septomaxilla, although the premaxilla forms the roof of the actual opening; neither maxilla nor lacrimal enters into its margins.

In many respects the pattern of the skull elements follows the "normal" pattern of generalized labyrinthodonts and need not be considered in detail. There is no median interfrontonasal element of the type found in *Eryops*. The postparietals (dermal supraoccipitals) extend far laterally, and the tabulars are small so that there is a broad supratemporal-postparietal contact. The septomaxilla is presumably primitive in that it has a well-developed sculptured surface exposure posterior to the external naris. The lacrimal is of a common rhachitomous type, well developed but not reaching the orbit; it is excluded from the naris because of the presence of a superficial portion of the septomaxilla. The squamosal extends far laterally, and the jugal and quadratojugal meet only in a relatively short transverse suture. The maxilla extends posteriorly to meet the quadratojugal in a short suture. The postfrontal is small.

An unusual feature is the presence of an intertemporal, rare in nonembolomerous forms. This is preserved only on the left side. Its outlines have been carefully checked by a study not only of the outer

[5] It was incorrectly assumed in the type description that these swellings were premaxillary in position.

surface but of the inner face of the bone, radial growth striations, and the sections shown on the breaks in the specimen. As usual, it occupies the general area covered by the posterior part of the prefrontal and the anterior part of the supratemporal when the intertemporal is absent.

The sutures between various skull-roof elements are seen from the inner side in Figure 2, although portions of the sutures are concealed

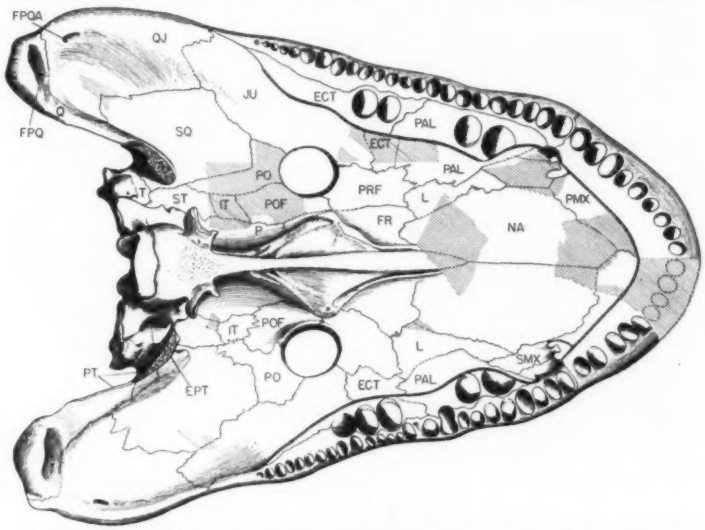


FIG. 2.—Ventral view of dermal roof. ×½. The palatal elements have been removed, except for their thickened lateral portions. Restored areas shaded. On the right side (*upper side*) the pterygoid and epipterygoid have been removed in their entirety, showing the rough ventral articular surface of the descending squamosal buttress (*A*). On the opposite side the section is at a more ventral level, showing the thickened portion of the epipterygoid which articulates with this flange and the thin sheet of pterygoid which lies posteromedial to it.

by the brain case and the more lateral portions of the roof are in part covered ventrally by palatal elements. It will be noted that in a number of instances there are marked overlaps, so that the internal sutural pattern differs considerably from that seen externally.

*Palate and palatoquadrate complex* (*Figs. 3–6*).—In the skull described much of the palate was preserved but broken into pieces,

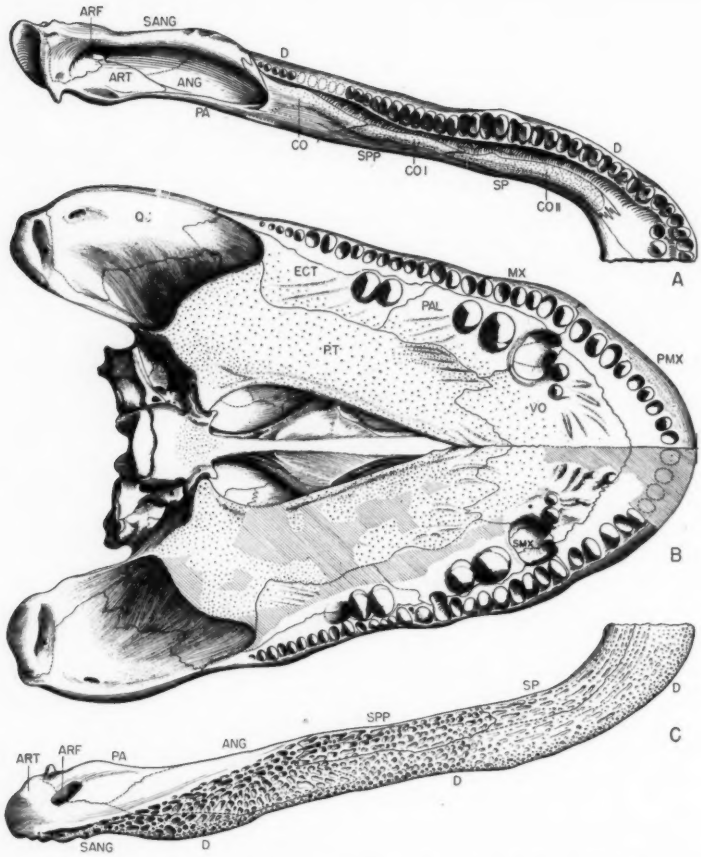


FIG. 3.—*A*, dorsal (internal) view of lower jaw. Crosses mark the position of upper-jaw fangs. *B*, palate; on the left (*lower*) side, only the known portions of the palate are indicated, the remaining areas hatched; on the opposite side the palate has been freely restored. Whether or not vacuities existed anteriorly for the anterior dentary fangs is uncertain. *C*, ventral (external) view of lower jaw. All $\times\frac{1}{2}$.

which were fitted with difficulty. On the left side of the palate in Figure 3, *B*, are shown those portions present in this specimen; on the right is an attempt at restoration of the entire structure.

Laterally are seen the ventral surfaces of marginal roofing elements—premaxilla, maxilla, and quadratojugal (the jugal does not enter the lower margin). The maxilla has little exposure beyond the marginal tooth row. The premaxilla has a moderate ventral exposure. The region of the median suture between the two premaxillae is not preserved, and hence one cannot be sure whether the pit or vacuity characteristic of this region in many labyrinthodonts for the accommodation of lower-jaw teeth was present or not; since, however, each jaw ramus bears a well-developed tooth pair here, such a pit may well have existed.

The marginal teeth are unusually large. They are subquadrate in basal contour and slant markedly outward toward the tips. Probably about 32–33 teeth were present in each ramus. The exact number in the premaxilla cannot be determined; the maxilla carried about 24. There is some evidence of the usual alternation of even and odd series of marginal teeth. The largest marginal teeth are those near the anterior end of the maxillary series, as in many early tetrapods; there is some suggestion of a secondary "peak" in tooth size farther back along the maxilla.

The general nature of the bony structures in the narial region may be seen from the palatal view and that of the under surface of the roof. The choanae are subcircular in outline and mainly bounded by the vomers and palatines, the maxillae form a small part of the outer wall, and the premaxillae barely enter the anterolateral corners. The inner half of the opening, mainly the vomerine portion, is a thickened rim of bone which has no connection with the roofing elements. Laterally the maxilla forms a continuous vertical wall; this wall is continued posteromedially by the palatines, which for much of their extent form a solid mass of bone extending dorsally to be firmly attached to the maxilla below the skull roof. As seen through the choana, the upper boundary of the choanal region is formed by the roofing elements, with the maxilla laterally, the nasal medially. Between the two is seen the ventral surface of the septomaxilla. As noted above, this bone dorsally becomes deeply grooved

toward its anterior end. The ventral surface, in corresponding fashion, develops a marked ridge anteriorly; this articulates at the anterior edge of the choana with the vomer. Between this point and the lateral margin there is a small opening leading forward to the region of the external naris. It will be noted that the external naris lies anterior to the position of the choana, and it is obvious that air in passing from surface to palate first passed forward and downward through the external naris and then had to be directed sharply backward to reach the choana. The lateral opening between septomaxilla and maxilla is too small to have accommodated such an air channel and presumably was utilized only by a branch of Nerve V and associated vessels; the air passage must have been medial to the septomaxilla. Unfortunately, the bones surrounding the nares have nearly smooth surfaces which give little evidence as to the structure of the cartilages of the nasal capsule. However, the undersurface of the roof shows a marked ridge, rounded in section, which crosses the middle of the septomaxilla and extends posteriorly and medially to the nasal; a second, less marked ridge lies posterior to and parallel to this on the lacrimal and nasal, and there is some evidence of a corresponding ridge on the adjacent upper surface of the palatine. These structures may indicate the posterior boundary of the nasal capsule.

The interpterygoid vacuities are notable for their small size; they are smaller than in any other described member of the Rhachitomi. Unique for this group is the structure at their anterior ends. In all other Rhachitomi their anterior margins are curved, and they are bordered here by the vomers with which the parasphenoid articulates. In *Edops* the anterior margins are V-shaped, and the two pterygoids meet in a median suture ventral to the anterior end of the parasphenoid. This is an embolomerous, rather than a typically rhachitomous, condition.

Three pairs of palatal fangs are present on each side of the palate, arranged, as is frequently the case in labyrinthodonts, as single pairs on vomers, palatines, and ectopterygoids. The palatine teeth are the largest of the series; the ectopterygoid teeth nearly as large; the vomerine pair much smaller.

In addition to these fangs, much of the palate is covered with a shagreen of smaller teeth. These cover most of the palatal aspect of

the pterygoid and extend on to the adjacent regions of the other bones. The skull illustrated showed a mass of partially ossified tooth-bearing tissue underlying the basal articulation, so that in life the tooth-bearing areas of pterygoid and parasphenoid appear to have been continuous in this specimen. In other smaller, and apparently less mature, specimens this tissue appears to be absent. A curious feature is the fact that the denticulation of the pterygoid is not restricted to the palatal aspect of the pterygoid but extends some distance on to the quadrate ramus of the bone (Fig. 4).

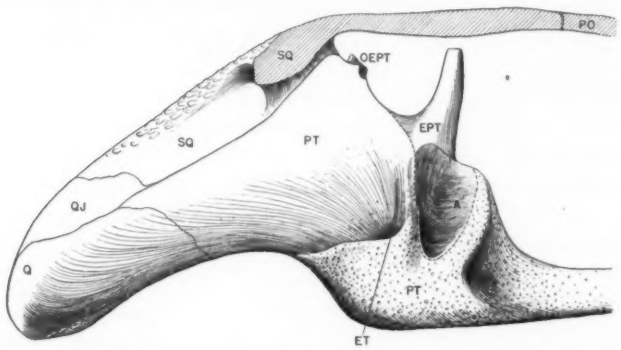


FIG. 4.—Medial view of the suspensorial region; the lateral wall of the skull omitted. ×⅔. The epipterygoid is in great measure concealed by the pterygoid; and the only parts visible are the tip of the otic process, the columnella cranii, and the concave articular surface (*A*) for the basipterygoid process.

The palatal elements show a series of low ridges which radiate from the fang pairs in the case of the lateral elements. Such ridges are also present on the adjacent portions of the pterygoid.

The median margin of the pterygoid is a thickened ridge adjoining the interpterygoid vacuity. The pterygoid flange is moderately thickened. Owing to the small size of the vacuities, the palatal rami of the pterygoids are broadly expanded. The vomer is a platelike structure with a thickened area beneath the fangs and a thickened rim extending back around the choana to the palatine articulation. This rim is pierced by a small foramen which passes forward from dorsal to ventral surfaces; presumably this carried a branch of the palatine nerve. Much of the palatines and ectopterygoids are thick

masses of bone which are in contact with the maxillae dorsally as well as laterally. In Figure 2 these elements are represented as if cut off medially close to the edge of the thickened portions. Palatine and ectopterygoid further send upward and medially thin flanges of bone, apparently rather variable in development, underlying the bones of the dermal roof. On the palatal surface palatine and ectopterygoid extend medially to articulate with the pterygoid and, in the case of the palatine, to meet the vomer behind the choana. On the dorsal surface of the palate the pterygoid is more restricted anteriorly, for both vomer and palatine considerably overlap it dorsally. On the other hand, the pterygoid overlaps the posteromedial border of the ectopterygoid to some extent dorsally.

As far as can be determined from sections seen in breaks in the material, a canal leading forward from the quadratojugal passes through the maxilla beneath the tooth row. Anteriorly this comes to lie between maxilla and the thickened portion of the palatine to open, funnel-shaped, into the posterolateral corner of the choana. The palatine is pierced medially by a foramen whose course cannot be definitely traced. These two openings have been interpreted by Säve-Söderbergh as filled by cartilaginous extensions of the nasal capsule. It seems more reasonable, however, to assume that the medial opening in the palatine carried nutrient vessels, while the funnel and the connecting canal in the maxilla contained the maxillary nerve and artery. The medial surface of the ectopterygoid is penetrated by a branching set of foramina which presumably afforded entrance for portions, at least, of the maxillary artery and nerve, although we have not determined the connections (if any) of these foramina with the longitudinal canal contained in the maxilla.

The broken condition of the palate makes it difficult to determine the possible extent of the cartilaginous palatal ramus of the palatoquadrate or the complete extent of the ossification of this ramus by the epipterygoid. This ossification, however, was unusually extensive for a rhachitomous amphibian, for one of the palatal fragments shows that the bone extended at least one-third of the distance forward from the region of the basal articulation to the narial region.

The thickest portion of the epipterygoid lies adjacent to the basal articulation. This element forms a deep socket for the reception of

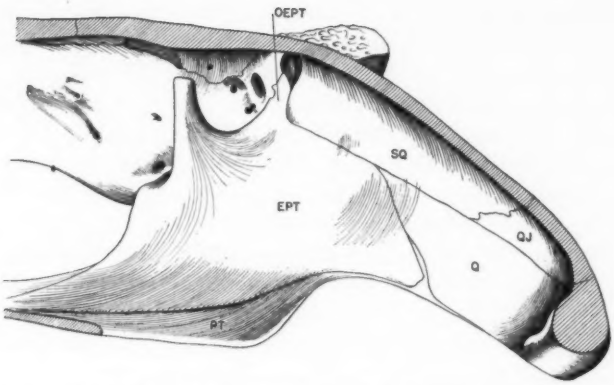


FIG. 5.—Lateral view of the suspensorial region, the dermal bones sectioned longitudinally through the quadrate. $\times\frac{2}{3}$.

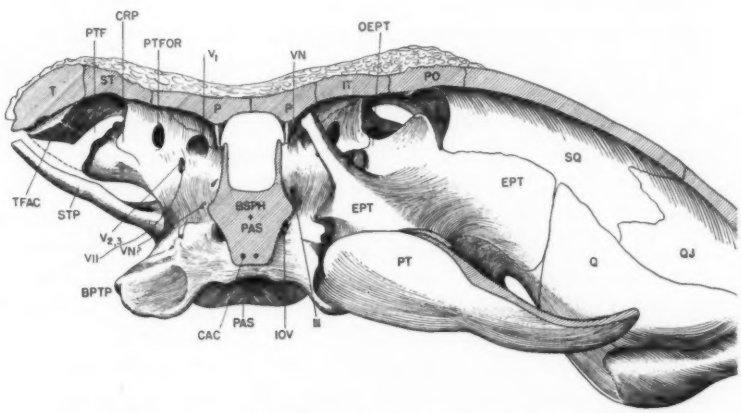


FIG. 6.—Anterior view of the posterior portion of the skull. $\times\frac{2}{3}$. The brain case is represented as sectioned just anterior to the pituitary fossa, and this transverse plane is continued to the right. On the left side of the figure the palatoquadrate has been removed and the roof sectioned diagonally backward to the otic-notch region. Details of the interior of the brain cavity are omitted. At the left the broken line indicates the ventral margin of the cartilaginous extension of the paroccipital process, which in life would have concealed the posttemporal fossa from view.

the basipterygoid; as in many early tetrapods, this socket includes two essentially plane surfaces approximately at right angles to one another, one surface facing downward and inward, the other rather dorsally and posteriorly, as well as inward. The epipterygoid socket is nearly completely surrounded by thick margins formed by the pterygoid. The two elements are well fused here but can be distinguished by differences in bone texture.

The epipterygoid has a well-developed ascending process, subcircular in section, which approaches but does not reach the dermal roof. More posteriorly there is a well-defined otic process which articulates over a very limited area with the parotic process of the otic capsule. Posterior to this point the epipterygoid rises still higher and thickens to present a broad dorsal surface which articulates with a thick buttress descending from the squamosal. Posteriorly the epipterygoid extends back as a wide but thin sheet of bone which gains a broad contact with the quadrate.

Applied medially to the epipterygoid is the still more expanded quadrate ramus of the pterygoid. In the region of the parotic process the pterygoid approaches the otic capsule closely, but there is no actual contact. There is a long contact dorsally with the squamosal and more posteriorly with the quadratojugal. Its distal portion overlaps medially the "otic" process of the quadrate. Just behind the basipterygoid articulation is a pronounced pocket in the medial surface of the pterygoid, which A. P. Bystrow and J. A. Efremov[6] have termed the "excavatio tympanica." There is no well-defined indication of the crista obliqua, which both these authors and Säve-Söderbergh have noted on the quadrate ramus in advanced labyrinthodont types.

The relations of the squamosal to the suspensorial region are shown in somewhat diagrammatic sections in Figure 2. From the inner end of the squamosal descends a thick buttress with a broad ventral articular surface; more distally the articular surface becomes much thinner. The buttress is met ventrally by a thickened ascending process of the epipterygoid. This is bounded medially by a thin sheet of pterygoid, which fuses with the squamosal on the medial

[6] "*Benthosuchus sushkini* Efr.: A Labyrinthodont from the Eotriassic of Sharjenga River," *Trav. Inst. Paleont. Acad. Sci. U.S.S.R.*, Vol. X (1940), pp. 1–152.

surface of the buttress. More distally, beyond the buttress, the area of epipterygoid articulation is reduced, and the contact of squamosal with pterygoid becomes broader.

The quadrate is well ossified, with a thickened articular portion and a long and relatively thin "otic process" which, as has been noted, is in contact with the epipterygoid, although there is no well-developed suture and cartilage tended to persist between them. The usual paraquadrate (quadrate) foramen was present and in addition an accessory paraquadrate foramen, noted otherwise, as far as I am aware, only in *Benthosuchus*.[7] Unfortunately, the main skull described is badly fractured in this area, and there appears to be considerable variation in other available fragments of this region so that details here are somewhat uncertain. Apparently, however, the paraquadrate foramen lies mainly in the quadrate rather than between that bone and the quadratojugal. The accessory foramen enters the quadratojugal from the inner surface but does not reach the outer side. Instead, it continues as a canal, which passes forward through the thickened lower margin of the quadratojugal and, as suggested by sections seen in fractures, may be continuous with the canal present in the lateral margin of the maxilla. In one instance, at least, the two foramina are connected by a further canal lying within the substance of the quadratojugal. A. P. Bystrow[8] has suggested that these foramina transmitted arterial vessels, but we do not feel certain of the details of his interpretation.

*Brain case* (*Figs. 4–11*).—The brain case is nearly completely preserved in No. 1378, and a number of fractures have fortunately allowed us to explore the internal surface. In many regions confirmatory evidence is afforded by other, more fragmentary remains. The side walls of the fore- and midbrain regions were somewhat damaged, but between the two sides almost the whole of this region could be satisfactorily determined.

The general proportions of the brain case are in many regards those seen in typical Rhachitomi, such as *Eryops*, with an expanded sphenethmoidal region, a constriction to a "waist" near the basi-

[7] *Ibid.*

[8] "Blutgefässystem der Labyrinthodonten," *Acta zool.*, Vol. XX (1939), Fig. 15.

pterygoid articulations, and a broad posterior expansion into otic and occipital regions. The brain case is, however, proportionately deeper, less platybasic, and hence closer to the presumed primitive type than in the flatter structural type seen in *Eryops* and later labyrinthodonts. Although it may be reasonably assumed that a number of ossification centers were present, there are no visible sutures except in portions of the occipital region.

As always, a well-developed parasphenoid is closely fused with the brain case ventrally. The cultriform process is little expanded anteriorly, and here the line of demarcation between parasphenoid and replacement bone of the brain case is readily visible. More posteriorly, the parasphenoid expands laterally so that it nearly completely ensheathes the basisphenoid core of the basipterygoid process (much as the pterygoid ensheathes the corresponding articular area of the epipterygoid). Posteriorly, the ventral portion of the parasphenoid ends with a broad free rim, of which the raised lateral corners are essentially tubera for the attachment of ventral neck musculature. The lateral borders of the parasphenoid behind the basipterygoid processes fuse into the sides of the otic capsule so that no definite boundary can be marked. The bone carries a shagreen of small teeth in the region adjacent to the basipterygoid processes; more anteriorly the surface is not preserved.

The dorsal surface of the brain case is nearly flat and for the most part has a complete roof beneath, and closely applied to, the dermal elements. In the supraoccipital region there is an unossified dorsal area, which was presumably filled by cartilage. In front of this region there is for a considerable distance a complete, although thin, roof in the position of a typical synotic tectum, and laterally this roof extends outward to cover the inner portion of the posttemporal fossa. More anteriorly there is a large fontanelle, reaching forward to the roots of the olfactory nerves. From this point forward the sphenethmoid region is solidly roofed, although in No. 1378 braincase roof and dermal bones do not gain close contact for about 1 cm. anterior to this point. At the sides of the fontanelle region the braincase walls do not reach the skull roof. Anteriorly and posteriorly the gap is closed by short descending flanges from the parietals; there persists, however, a longitudinal slit opposite part of the fore- and

midbrain regions, which may have afforded passage for Nerve IV and possibly a vein but appears to have been otherwise unimportant.

The sphenethmoid region is diamond-shaped, as seen in dorsal or ventral view. It is mainly a solid mass of bone, pierced by a pair of large divergent canals for the olfactory nerves; in contrast to *Eryops*, there is no subdivision of these canals. Anterior to the broadest portion of the sphenethmoid, these canals open into gradually fading grooves or the lateral surface of the bone. At its broadest portion the bone is pierced by short canals, which appear to have carried the profundus nerve forward into the ethmoid region. The brain case was obviously continued anteriorly and laterally in cartilage, the continuations of the curving lateral margins forming a planum antorbitale; as noted earlier, however, there are few data upon which to base any reconstruction of nasal and ethmoidal regions.

In *Eryops*[9] the internal carotid artery, palatine artery, and palatine nerve appear to have passed forward beneath the basipterygoid process in a groove on the under surface. In *Edops* the latter two structures appear to have followed a similar course, but the internal carotid enters a foramen in the parasphenoid near the back margin of the basipterygoid process—a situation apparently present in a large proportion of the older amphibia. Thence the artery runs forward (as clearly seen in fragmentary specimens) between parasphenoid and basisphenoid, the two carotids converging but not meeting anteriorly. At a point somewhat anterior to the basipterygoid processes and pituitary fossa the carotids enter the primary carotid foramina, turning sharply upward in the substance of the basisphenoid to enter paired pockets beneath the forebrain, where branching occurs. Two pairs of openings from these pockets reach the surface of the sphenethmoid region, and the further, forward course of the contained vessels is indicated by grooves. The upper vessel presumably was an optic artery, the lower an ophthalmic (in contrast to the modern anuran condition of a single artery taking the place of these two).

There is a well-developed transverse canal of primitive type for the anastomotic (interorbital, pituitary, or hypophysial) vein con-

[9] Cf. Sawin, *op. cit.*

necting the two surfaces of the brain case immediately anterior to the basipterygoid processes and curving slightly internally to pass just back of the pituitary fossa. In *Eryops* this channel is present in somewhat flattened form; in modern Anura it is absent, perhaps in relation to the highly platybasic condition.

The optic nerve appears to have emerged from an area of the lateral wall which was quite thin and has been damaged so that the exact contours of the opening are not preserved. Farther posteriorly are foramina which appear to have carried Nerves III and VI. Above, at the contact between brain case and parietal, there is on one side of the specimen one small opening, on the other a pair of similar openings; these may have carried small veins. More posteriorly, in the position of the pro-otic foramen of a modern anuran, we find three openings, which we may interpret as carrying Nerves $V_1$, $V_{2-3}$, and VII (there is no indication of a separate opening for the palatine branch of the facial nerve).

The stout basipterygoid processes were, as noted, articulated with the palate and consist of a core of endochondral bone, surrounded, except dorsally, by bony tissue continuous with the parasphenoid. As on the corresponding portion of the epipterygoid, the articular surface consists of two areas; one faces downward, outward, and forward and the other rather dorsally and posteriorly. The depression over the top of the process at its base appears to represent the course of the lateral head vein; a groove on the posterior margin of the process may indicate the downward course of the palatine branch of Nerve VII.

The occipital aspect of the brain case is seen in Figure 7. The condyle structure is comparable to that of an embolomere rather than a typical rhachitomous form. The lateral portions are situated on the exoccipitals, but the basioccipital also contributes a ventral portion continuous with them. The condyle is thus a single subcircular structure, although the lateral margins project somewhat more prominently. The center of the condyle is hollowed out in funnel fashion, so that notochordal material was obviously present. The basioccipital is incompletely ossified dorsally in its anterior portion, and the two exoccipitals, which (in presumably primitive fashion) form a partial floor to the posterior end of the brain case, do not meet

in the midline; a plug of cartilage persisted here between the three elements. Ventrally the basioccipital, shaped rather like a large intercentral element of the column, was sheathed in its more anterior portion by the parasphenoid; a specimen in which the two are separated shows that they interlocked in a system of parallel ridges and grooves such as are sometimes seen on the parasphenoid in forms in which the basioccipital is unossified.[10] Anteriorly the basioccipital is feebly ossified, so that (as in *Eryops*) a deep cleft, presumably

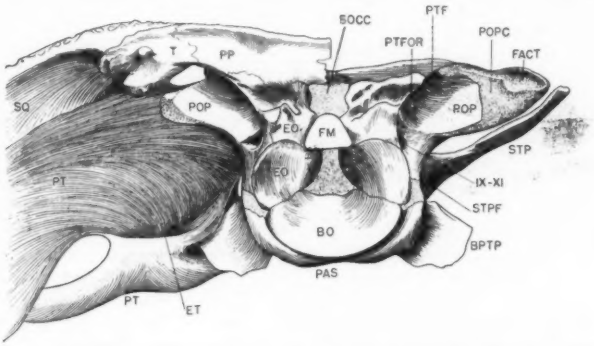


FIG. 7.—Occipital view. ×⅔. On the left the dermal roofing bones are present, and part of the suspensorial region is indicated. On the right the dermal bones have been removed. Cartilaginous areas above and below the foramen magnum are restored. On the left the paroccipital region is shown as preserved; on the right its cartilaginous portion is restored. The stapes is shown on the right side.

filled in life by cartilage, was present between the basioccipital and the basisphenoid region (cf. Fig. 10). This unossified gap is a characteristic feature of skulls as far removed as crossopterygians, on the one hand, and such primitive reptiles as pelycosaurs, on the other.

Above the region of the condyles the two exoccipitals extend upward as stout pillars on either side of the foramen magnum and reach the skull roof, where they extend forward beneath the postparietals to merge into the upper surface of the otic region of the brain case; there is no appreciable development of occipital flanges of the postparietals. The posterior surface of the exoccipital is sculp-

[10] Bystrow, "*Dvinosaurus* als neotenische Form der Stegocephalen," *Acta zool.*, Vol. XIX (1938), Fig. 2, facies cristata.

tured in an irregular fashion which varies in different specimens; in general, however, there is a distinct transverse ridge at about the level of the top of the foramen magnum. There is no distinct evidence of a proatlantal articulation. Medially the exoccipitals form, in their lower portions, a smooth wall for the postvagal region of the medulla. Dorsally the two elements converge to some extent but do not meet, leaving a space above the foramen magnum filled in life with a block of supraoccipital cartilage. At the junction of wall and floor each exoccipital is pierced by two small foramina, reasonably

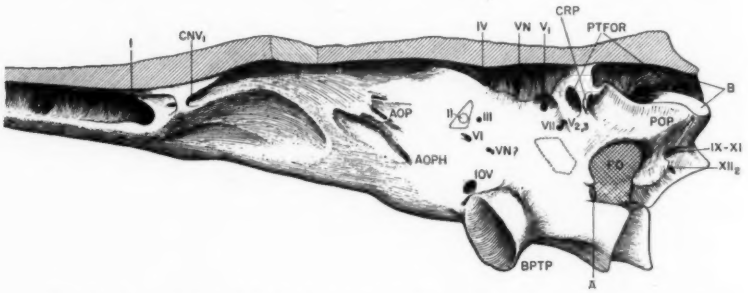


FIG. 8.—Lateral view of the brain case. ×⅔. The walls of the sphenoid region were incomplete in the specimen, but between the two sides all areas were present except the two enclosed in broken lines. *A*, perichondral bone sheet continuous with stapes. *B*, unfinished surface of paroccipital process, presumably continued in cartilage.

interpreted as for the hypoglossal roots; the more posterior reaches the lateral surface of the occiput independently, the anterior one fuses with the vagus canal. This latter, presumably carrying Nerves IX–XI, as well as a posterior cerebral vein, is definitely placed between the exoccipital and the posterior margin of the osseous ear capsule. The two elements concerned are readily separable below the foramen. Above the foramen, however, they are fused in the available material. The exoccipital spreads out to some extent at its upper end over the posttemporal fossa.

The brain case is greatly expanded in the otic region. Presumably pro-otic and opisthotic elements were present, but they are not separable by suture, and, further, there are no sutures clearly separating the otic region from other portions of the brain case except for the suture with the lower part of the exoccipital.

Low down on the lateral aspect is the large fenestra ovalis. The dorsal and lateral margins of this opening are clearly defined and well ossified; ventrally, however, the margins are incomplete. Here

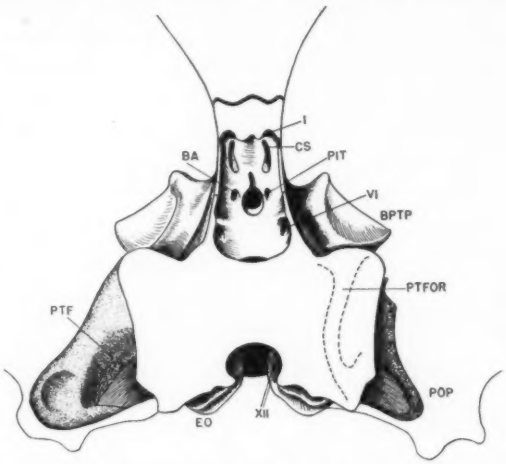


FIG. 9.—Dorsal view of posterior portion of brain case. ×⅔. On the left the cartilaginous extension of the paroccipital process is restored. The course of the posttemporal foramen is indicated on the right by broken lines. The outlines of the dermal skull table are indicated.

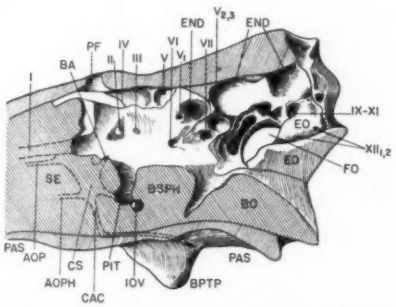


FIG. 10.—Median section of the posterior portion of the brain case. ×⅔

there is a ventral extension of the otherwise subcircular fenestra, bounded ventrally, as the specimen is preserved, by the rim of the parasphenoid. This area was occupied by a corresponding ventral expansion of the stapedial footplate. At the anterior edge of this re-

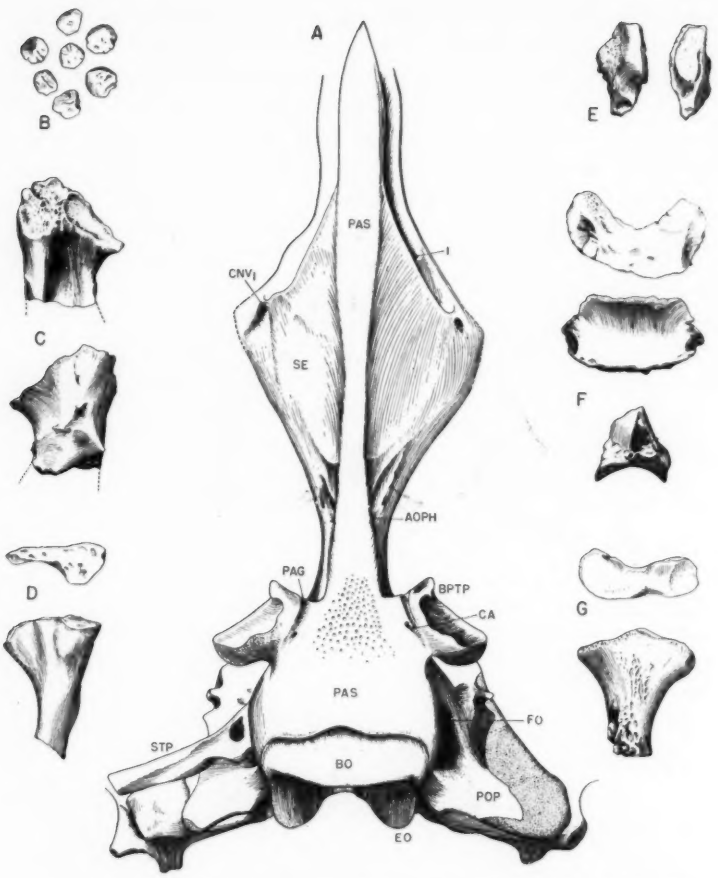


FIG. 11.—*A*, ventral view of brain case. The stapes is present on the left side of the figure. On the opposite side the cartilaginous portion of the paroccipital process is restored. *B*, dermal ossicles. *C*, head of left sacral rib, inner and outer views. *D*, *G*, rib heads, lateral and proximal views. *E*, right pleurocentrum, lateral and anterior views. *F*, intercentrum, anterior, ventral and left lateral views. All $\times\frac{2}{3}$.

gion the stapes was continuous with the superficial portion of the adjacent area of the brain case. A comparable condition of an incomplete ventral ossification of the margins of the fenestra is found in pelycosaurs and probably in other early reptiles.

The general structure of the paroccipital region is comparable to that of *Eryops;* but, although the tabular has no occipital flange, the distal end of the process is unossified, suggestive of conditions in later types of labyrinthodonts. On the left side of Figure 7 the bones are shown as preserved. The distal and anterior edges of the process are unfinished and indicative of a cartilaginous continuation reaching up laterally beneath the tabular and thence forward and inward. It thus formed an anterior wall to the fossa between the upper surface of the paroccipital and the skull roof—a wall found in ossified condition in *Eryops*. This cartilage is restored on the right side in Figures 7 and 11 and on the left in Figure 9.

The fossa so enclosed has usually been termed the "posttemporal fenestra." It is, however, not simply a "window" as in reptiles, but a deep pocket extending far forward over the otic region, which may be, as Säve-Söderbergh suggests, homologous with the "fossa Bridgei" of fishes—an area of origin for neck musculature. The term "posttemporal fossa" appears to be an appropriate one for this structure.

The fossa communicated with the temporal region (much as in *Eryops*) by a foramen which may be termed the "posttemporal foramen," leading forward from the inner portion of the fossa to open on the anterior face of the capsule lateral to the foramen for Nerve V. As is usually assumed, this channel may have carried a dorsal vein draining the blood forward from part of the occipital musculature. Bystrow[11] assumes that the vena capitis lateralis passed back through this foramen. This seems to be due to a misinterpretation of conditions in the urodeles, upon which his reconstruction is based; the urodele vein appears to follow the normal course backward ventrally between palatoquadrate and capsule in the cranioquadrate passage.[12] The opening is, nevertheless, one of considerable size—

[11] "Blutgefässystem der . . . . ," *op. cit.*, p. 138 and Fig. 13.

[12] E. T. B. Francis, *The Anatomy of the Salamander* (Oxford: Clarendon Press, 1934), p. 222, antrum petrosum laterale.

larger than would be expected for a vein merely draining a small area of musculature.

On the anterior surface of the capsule lateral to the opening of the posttemporal foramen is the small but distinct crista parotica articulating with the otic process of the epipterygoid.

The internal structure of the brain case is shown in Figure 10 but will not be discussed here in detail, since the endocast derived from it is described elsewhere.[13]

STAPES

The stapes is well preserved in No. 1378. The main portion of the footplate is essentially oval in contour; ventrally, however, there is an additional area corresponding to the ventral portion of the fenestra, at the anterior margin of which the stapes is in continuity with the bone of the adjacent margin of the brain case. This condition is reported in other labyrinthodonts and may well be a primitive one. A stapedial foramen of good size is present. The upper surface of the shaft is incised diagonally by a large channel which presumably formed the lower margin of the passage through which passed the vena capitis lateralis and the hyomandibular trunk of the facial nerve. The distinct crest at the distal edge of this channel appears to have been closely applied to the paroccipital process of the otic capsule and hence corresponds to the dorsal head of the stapes seen in much more highly developed form in both crossopterygians and pelycosaurs. Its reduced form in this type of labyrinthodont is, of course, due to the fact that the shaft passes close to the paroccipital, and hence no elongation is necessary to produce such a dorsal contact (presumably ligamentous). When articulated, the shaft is seen to be directed into the otic notch. The tip of the shaft is unfinished and hence may have been continued in cartilage.

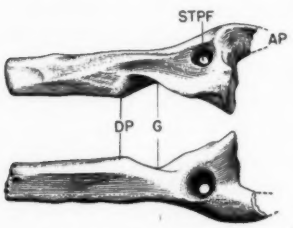


FIG. 12.—Right stapes, posteromedial and anterolateral views. ×½.

[13] Romer and T. Edinger, "Endocranial Casts and Brains of Living and Fossil Amphibia," *Jour. Comp. Neurol.*, Vol. LXXVII (1942), pp. 355–89.

LOWER JAW (FIG. 3, *A*, *C*)

One nearly complete ramus and part of the other are present in No. 1378; this, with numerous fragments from other specimens, shows the nearly complete jaw structure except for details at the level of the anterior part of the mandibular fossa, where the only specimen preserving this region is badly crushed and broken. In its general anatomy and the nature and mutual relations of the elements present, the jaw is that of a characteristic member of the Rhachitomi. The one major peculiarity is the fact that the jaw is greatly flattened anteriorly, so that the morphologically external surface faces ventrally.

The marginal dentition includes about 44 teeth. The dentary also bears, close to the symphysis, a pair of fangs of moderate size—rather larger than those of *Eryops*. In correlation with the anterior flattening, the symphysis is moderately elongate; the splenials form a substantial part in the symphysis. The usual series of three coronoids is present. These elements bear numerous small teeth of the type seen on the palate. The tooth-bearing areas are raised and sharply demarcated from the rest of the coronoid surface. Between the tooth-bearing area of the coronoids and the marginal tooth row is a well-defined longitudinal groove of irregular width. Expansions of this groove correspond to the position of the palatine and ectopterygoid fangs of the upper jaw.

The prearticular appears to have extended well forward, although imperfections, as noted, make it impossible to be sure of the exact contours of this bone in its middle portion or of the outlines of the infra-Meckelian fenestra.

Posteriorly the jaw shape changes from the flattened condition seen in front to a more normal upright build. In larger and more mature specimens the articular is well fused with all three adjacent dermal elements—prearticular, surangular, and angular—but numerous fragmentary specimens, some rather small and immature, enable us to make out most of the structure. The articular is well ossified, forms the transversely placed, concave articular surface and the "lips" surrounding it (there is no retroarticular process), and extends as a flattened, triangular process well forward in the floor of the mandibular fossa. The margins of this process are well defined

except at its narrow tip. The outlines, as well as a prominent groove on the angular which continues forward its lateral margin, indicate that there was but a small extent of Meckelian cartilage anterior to the ossified area. The articular is widely overlapped anterodorsally in the fossa by the surangular, which forms a stout buttress in front of the bone in the articular region and runs down into the floor of the mandibular fossa. The prearticular, angular, and surangular join to sheathe the ventral surface of the Meckelian process of the articular. In contrast, however, with many later labyrinthodonts, the articular is widely exposed on the surface of the jaw posteriorly. The canal common in this region in all early tetrapods is present, passing diagonally inward and backward on the medial surface and then curving forward to open laterally in the floor of the mandibular fossa. For the most part, at least, the foramen follows a course between the articular and the adjacent dermal bones—surangular and prearticular. This foramen is generally assumed to be for the chorda tympani nerve. It is here, however, of large size and may reasonably have carried blood vessels as well as nerve. We, therefore, prefer to use for it the noncommittal term of "para-articular foramen" (by analogy with the closely comparable paraquadrate [or quadrate] foramen of the upper jaw).

The senior author has elsewhere[14] commented on the mirror-image relationship of upper and lower jaw structures in early tetrapods. In *Edops* the elements of the posterior end of the lower jaw are highly comparable to those of the suspensorial region—articular to quadrate, surangular to quadratojugal, prearticular to quadrate ramus of pterygoid. There is, however, no observable structure in the lower jaw comparable to the accessory paraquadrate foramen.

### NOTE ON RECONSTRUCTIONS OF SOFT ANATOMY

In the preceding sections considerable information has been given which is of aid in the interpretation of the soft anatomy of the cranial region. We have not, however, attempted to present a detailed reconstruction of the cranial angiology or neurology. Two attempts at such reconstructions of labyrinthodonts are available, those of G.

[14] Romer, "Mirror Image Comparison of Upper and Lower Jaws in Primitive Tetrapods," *Anat. Rec.*, Vol. LXXVII, No. 2 (1940), pp. 175–79.

Säve-Söderbergh[15] and Bystrow,[16] the latter confining himself to angiology. We believe heartily in attempts to restore the soft parts of fossil forms, for they are likely to lead to valuable results in the study of the general evolution of the nervous system, circulatory system, musculature, etc. The value of any reconstruction, however, depends upon (1) the amount of pertinent osteological data available and (2) the breadth of the comparisons made with living types.

The studies cited may be criticized on both grounds. Both authors have perforce used advanced labyrinthodonts as the bases for their reconstructions. In these forms there is almost no ossification in the endochondral skeleton, and hence most of the important landmarks by which the course of soft structures may be plotted are absent. If, for example, one seeks the evidence upon which Säve-Söderbergh's detailed figure of the labyrinthodont cranial nerves is based, it is found to be almost nonexistent. He has reconstructed the cartilaginous endocranium, supplied it with hypothetical foramina, and in turn filled these with an appropriate series of nerves.

Further, in neither case has comparison been made with other than a single type of modern amphibian. Säve-Söderbergh's figures are of the frog's nervous and arterial system, slightly modified to fit into a labyrinthodont skull; Bystrow's reconstructions are frankly based on the urodele. The frogs are probably related to labyrinthodonts but may well have become as highly modified in their soft structure as in their skeletons, and the urodeles may well be even further from the ancestral stock. Properly, the interpretation of the soft anatomy of early tetrapods should be based on a comparison with both major modern amphibian groups, a consideration of the features present in the early reptiles, likewise of labyrinthodont descent, and, finally, of antecedent conditions, as far as they may be deduced, in the fish ancestors of the tetrapods.

### AXIAL SKELETON

No adequate articulated material of the axial skeleton has been discovered, but numerous isolated vertebral elements exist. These

[15] "On the Morphology of Triassic Stegocephalians from Spitzbergen, and the Interpretation of the Endocranium in the Labyrinthodontia," *Svenska Vet. Akad. Handl.*, Vol. XVI, No. 1 (3d ser., 1936), pp. 1–181.

[16] "Blutgefässystem der . . . . ," *op. cit.*

are mainly from the Cottonwood Creek locality. At that place there have been recovered many elements of rhachitomous vertebrae. These readily sort into two series. One includes elements of relatively smaller size, which obviously pertain to *Eryops*. The second includes larger elements, different in morphological structure, which are reasonably interpretable as pertaining to *Edops*. This seems to be rendered certain through the finding of a few elements of similar nature with specimens 1235, 1770, and 1378. The intercentra (Fig. 11, *F*) differ notably from those of *Eryops*. They are much flatter ventrally, and the facets for rib articulation are much larger and more distinct. In *Eryops* the anterior and posterior margins of the ventral surface are sharply downturned, rendering this surface markedly concave; in *Edops* little of this downturning is seen. Further, they are less well ossified internally. A typical *Eryops* intercentrum, when seen in anterior or posterior view, is but slightly notched centrally between the two ascending "horns"; the *Edops* intercentra are more crescentic in shape, with a large central cavity. This may indicate a larger notochord but, more probably, means merely that a greater amount of basiventral cartilage persisted. From the caudal region there are intercentra with the bases of the haemal arches, but none is complete.

The pleurocentra (Fig. 11, *E*) have a structure essentially similar to that of *Eryops*, but there are readily distinguishable features. As in the intercentra, the margins of the superficial surface are much less outturned in *Edops* than in the former genus. The thin ventral extension of the pleurocentrum is more developed than in *Eryops*. The flattened facet opposed to the arch pedicel is relatively narrower but more elongated dorsoventrally.

The neural-arch elements are incompletely preserved and are not figured here. It appears that the spine differs from that in *Eryops*, but better material is needed before a diagnosis of value can be made. In the pedicel of the arch in the presacral series the rib facets are much broader than in *Eryops* and approach a subcircular form, rather than the long, thin, rectangular shape seen in that genus. On the other hand, the area beneath the rib articulation, which faces the pleurocentrum, is relatively poorly ossified and smaller in area than in *Eryops*.

Ribs are known only from their heads, of which several are figured (Fig. 11, *D*, *G*). The typical dorsal ribs appear to have been less flattened in the proximal portion of the shaft than in *Eryops* and are nearly circular in section. The capitular and tubercular facets are more rounded in contour than in *Eryops*.

Two examples of the articular portion of the sacral rib are preserved (Fig. 11, *C*). This element appears to have been fundamentally similar to the type seen in *Eryops* but is readily distinguishable. On the medial surface of the head region the rib of *Eryops* is gently concave; this region in *Edops* forms a deep depression, and, conversely, the external surface is much more convex than in *Eryops*. A marked external rugosity near the capitular border of the "neck" of the rib has no parallel in *Eryops*.

### APPENDICULAR SKELETON

Only fragments of the appendicular skeleton are available. The pectoral girdle is almost unknown. Of the pelvic girdle, the basal portion of the ilium is present in a well-preserved fragment from Cottonwood Creek, and No. 1770 includes a specimen with a good part of the acetabular area (Fig. 14, *D*); in this, however, little detail can be seen. The acetabular area and the "neck" above it are of characteristic primitive tetrapod pattern and not dissimilar to *Eryops*. The base of the iliac blade, as preserved, expands rapidly both anteriorly and posteriorly. The fragment may be so articulated as to suggest an iliac blade, shaped like that of *Eryops*. However, the posterior margin ceases at about the position in which in *Eryops* one finds the tip of a posteriorly directed process. But in *Edops* this area is thick, and there may have been a broader type of iliac blade or a more highly developed posterior process.

The humerus (Fig. 13) is best known from No. 1781, a nearly complete element which appears to have belonged to a large individual; the greatest length is about 18 cm. A nearly complete but smaller specimen (with a length of 16 cm.) is included in No. 1770; this has preserved certain portions of the bone not present in No. 1781, but the difficult matrix obscures much detail. The element is of the typical, primitive tetrahedral type common to most contemporary tetrapods but differs markedly from *Eryops*. In general, one may

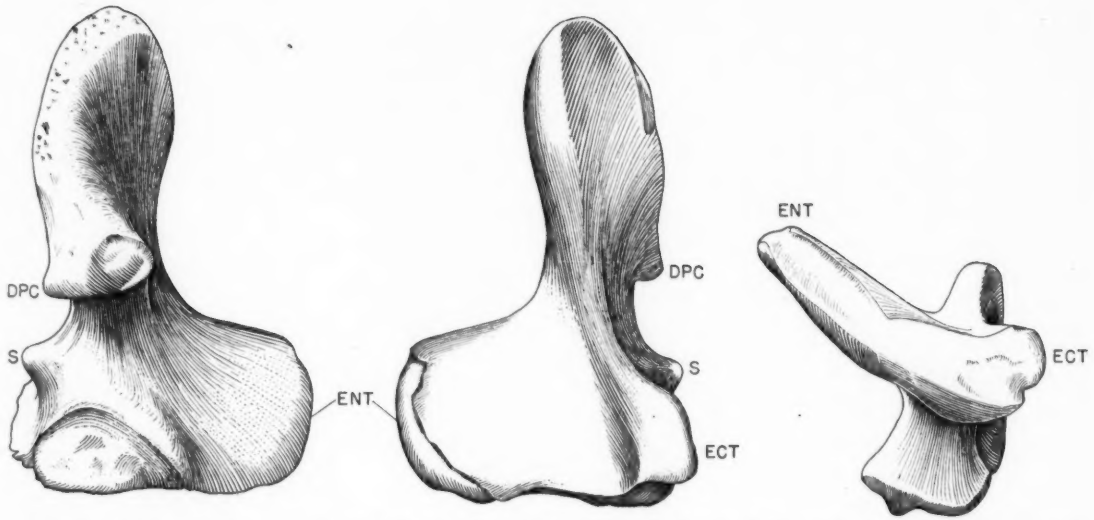


FIG. 13.—Right humerus, ventral, dorsal, and distal views. *DPC*, deltopectoral crest; *ECT*, ectepicondyle; *ENT*, entepicondyle; *S*, supinator process. $\times\frac{2}{3}$.

say that the bone is much less "bumpy," with less pronounced muscular processes and rugosities. The distal end is less sharply twisted on the proximal than in *Eryops*, and there is more development of a shaft region. The supinator crest is less prominent than in *Eryops* and is connected by a continuous ridge with the deltopectoral crest; the condition is intermediate between that seen in *Eryops* and that seen in *Cricotus*. The ectepicondyle is much less elevated than in *Eryops*.

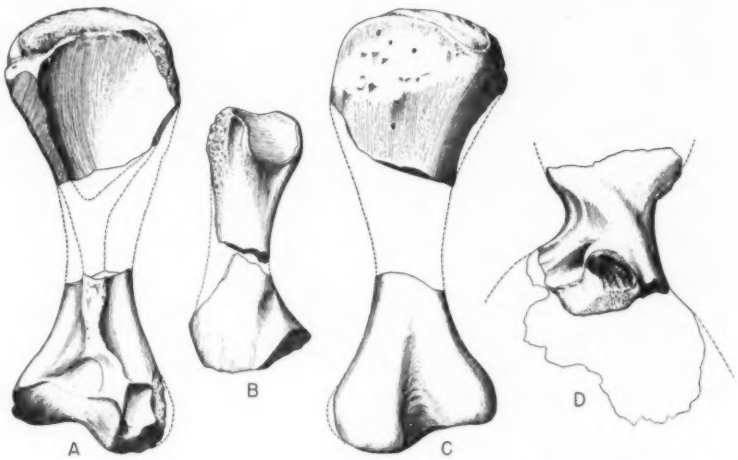


FIG. 14.—*A*, right femur, ventral surface. *B*, right fibula, external view. *C*, right femur, dorsal surface. *D*, incomplete right ilium. The shaded portion based on a specimen from Cottonwood Creek; the unshaded area is present in a second specimen in which, however, the surface is not preserved. All ×⅓.

Radius and ulna are almost unrepresented except for No. 1770, where these elements are present, articulated with the humerus noted above. These have lengths of approximately 75 and 97 mm., respectively. They are enclosed in a film of refractory matrix which has not been removed, and little can be said of their detailed characters.

The femur (Fig. 14, *A*, *C*) is known only from fragments of the ends, from which a composite restoration is figured. The bone is obviously flatter distally than in *Eryops* and with the longitudinal ad-

ductor ridge ("linea aspera") much less elevated. In relation to the relative flattening of the distal end, the fibular articular area faces much more ventrally than in *Eryops;* proximal to this area is a deep pocket not present in that genus. Unfortunately, little can be said of the state of development of the proximal part of the ventral-ridge system.

Of the tibia only the head has been identified. This exhibits the general rhachitomous type of structure but with less development of depth in the medial articular region. A fibula (Fig. 14, *B*) apparently associated with M.C.Z. 1378 is nearly complete, and details missing can for the most part be supplied from other fragments. The bone is in some features comparable to that of *Eryops* but is relatively broader. At the head the structure is markedly different from that of *Eryops*. The articular area extends farther down the inner (or tibial) aspect and tends to a subcircular form rather than the elongate oval seen in *Eryops*. The usual rugosity on the external aspect of the head is found at the postaxial margin; and beneath this area, on the flexor aspect, is a distinct longitudinal groove not seen in *Eryops*.

A few carpal and tarsal elements and numerous metapodials and phalanges are present in the material from the Cottonwood and Padgett localities. We cannot, however, clearly distinguish at present the *Edops* specimens from those pertaining to *Eryops*.

### DERMAL ARMOR

We have not found in our material any trace of normal ventral dermal scales of the type usually found in labyrinthodonts. This, however, is not surprising in view of the lack of undisturbed postcranial material and the delicate nature of isolated scales. (We may note that even in the case of *Eryops* the dermal scales are but rarely found.) Evidence of a second type of dermal armor is, however, present. In the Cottonwood Creek locality, where fragmentary remains of *Edops* are plentiful, there are found numerous lens-shaped bony ossicles with an average diameter of 8–10 mm. (Fig. 11, *B*). One surface tends to be relatively flattened but with irregular furrows and tiny openings presumably for nutrient vessels. The other side is much more convex, often with a distinct raised area, and rela-

tively smooth. A majority are subcircular in outline, others have varied, more distinctive contours. Presumably these elements are dermal ossicles, situated in the corium of the back and flanks and very probably superficially situated, the convex surface external. There is, of course, no evidence as to details of their arrangement. That these ossicles are associated with *Edops* seems certain from the fact that they are abundantly represented in No. 1769, a specimen definitely ascribable to *Edops*.

### PHYLOGENETIC POSITION OF "EDOPS"

From the description above it is obvious that *Edops* is a very primitive member of the Rhachitomi, to which group it may be definitely assigned on the basis of vertebral structure. It is comparable to *Eryops*, *Actinodon*, and other characteristic Lower Permian rhachitomes rather than to more advanced or more specialized forms in a number of regards, such as general skull shape, lack of multiplication of lateral palatal teeth, well-ossified brain case, etc. The only feature in which *Edops* is further "evolved" (in the direction of degeneracy) than *Eryops* is the incomplete ossification of the paroccipital and supraoccipital regions. On the other hand, *Edops* is much more primitive than typical rhachitomes in a number of features. These include, among others, (1) presence of an intertemporal, (2) retention of a sculptured septomaxilla, (3) movable basipterygoid articulation, (4) unusually small interpterygoid vacuities, with (5) the pterygoids meeting anteriorly, (6) unusually well-ossified epipterygoid, (7) less platybasic brain case, with which is associated (8) a deep pituitary fossa and (9) a single occipital condyle. In all these features *Edops* approaches or reaches conditions presumably present in ancestors of the rhachitomes in an "embolomerous" stage of morphological development.

Of Permian types, *Trimerorhachis* has kept certain of these primitive features, including retention of the intertemporal and, apparently, a persistence of the movable basipterygoid articulation. This form is, however, quite degenerate in other regards, although it may well have been derived from an *Edops*-like ancestor.

For closer relatives of *Edops* we must turn to Carboniferous forms.

Most closely comparable of well-described types is *Dendrerpeton* of the Joggins of Nova Scotia.[17] This is likewise rhachitomous, although the vertebral structure is not of the usual type. The skull roof is comparable to that of *Edops*, but in the fact that the lacrimal still reaches the orbit *Dendrerpeton* is slightly more primitive. The occiputs are closely comparable; particularly noteworthy is the common presence of the primitive single condyle. In both the basal articulation is movable, and in *Dendrerpeton* the interpterygoid vacuities are unusually small for a rhachitome. Here, however, *Edops* is much more primitive, for in *Dendrerpeton* the anterior end of the palate is figured as being formed in typical rhachitomous fashion, with the pterygoids separated and with curved anterior margins of the vacuities formed by the vomers.

In the same general category as *Edops* and *Dendrerpeton* may be placed *Cochleosaurus* of Nýřany, as redescribed by Steen.[18] Here the brain case is unfortunately poorly known; the intertemporal is still present; the lacrimal is barely excluded from the orbit. The palate, however, shows a more developed pair of interpterygoid vacuities, the condyle appears to be attaining the double condition, and on the whole *Cochleosaurus* is rather more advanced toward the typical rhachitomous condition.

Several other forms from the Joggins and Nýřany, described by Steen, exhibit a skull-roof pattern which, in the presence of an intertemporal and a tabular of small size, is comparable to that of the primitive Rhachitomi already mentioned. For the most part, however, these are too poorly known to render further discussion profitable. Of interest, however, is *Capetus*, a Nýřany genus described by Steen[19] on the basis of a skull table. To this, she notes, may well be assigned an imperfect skull described by F. Broili[20] in error as *Sclero-*

[17] M. C. Steen, "The Amphibian Fauna from the South Joggins, Nova Scotia," *Proc. Zoöl. Soc. London*, Part III (1934), pp. 465–504.

[18] "On the Fossil Amphibia from the Gas Coal of Nýřany and Other Deposits in Czechoslovakia," *Proc. Zoöl. Soc. London*, Ser. B, Vol. CVIII, Part II (1938), pp. 205–83.

[19] *Ibid.*, pp. 241–42, Fig. 27.

[20] "Über *Sclerocephalus* aus der Gaskohle von Nürschan und das Alter dieser Ablagerungen," *Jahrb. geol. Reichsanst. Wien*, Vol. LVIII (1908), pp. 49–70.

*cephalus credneri*. A still better specimen, which is probably assignable likewise to *Capetus*, although omitted by Steen from her discussion of the Nýřany material, is a skull roof repeatedly figured by O. Jaekel[21] and compared by him with *Chelydosaurus vranii*. The skull table is closely comparable with that of the Steen and Broili skulls of *Capetus*. The entire roof pattern is almost identical with that of *Edops*, and it is reasonable to believe the two closely related.

*Edops*, then, is a very primitive member of the Rhachitomi. Except for the withdrawal of the lacrimal from the orbit, it shows every major feature to be expected in the ancestor of any rhachitomous or stereospondylous labyrinthodont and in skull structure bridges much of the gap between the Rhachitomi and their ancestors in a morphologically embolomerous (although non-anthracosauroid) condition. *Dendrerpeton* is related but more advanced in palatal structure; *Cochleosaurus* is apparently somewhat more advanced toward typical rhachitomes, and *Trimerorhachis* represents a degenerate side branch from the *Edops* stage. Since forms of more advanced type were already present in Westphalian or early Stephanian times, the genus *Edops*, which is apparently late Stephanian in appearance, cannot be considered as generically ancestral to them. We have noted that *Edops* is confined to the lowest levels of the Texas redbeds deposits. It thus appears to have been a late survivor of a group of Pennsylvanian ancestral rhachitomes.

[21] *Die Wirbeltiere* (Berlin: Borntraeger, 1911), Fig. 124; and "Über den Bau des Schädels," *Verh. anat. Gesellsch* (1913), Fig. 5.

## ABBREVIATIONS FOR FIGURES

| | |
|---|---|
| ANG. | angular |
| AOP. | optic artery |
| AOPH. | ophthalmic artery |
| AP. | anterior process of stapes |
| ARF. | para-articular foramen |
| ART. | articular |
| BA. | basilar artery |
| BO. | basioccipital |
| BPTP. | basipterygoid process |
| BSPH. | basisphenoid |
| CAC. | canal for carotid artery |
| $CNV_1$. | canal carrying n. ophthalmicus profundus forward through sphenethmoid |
| CO, CO. I, CO. II | coronoid elements |
| CRP. | crista parotica |
| CS. | pocket in which internal carotid branches |
| D. | dentary |
| DP. | dorsal process of stapes |
| ECT. | ectopterygoid |
| END. | position of endolymphatic sacs |
| EO. | exoccipital |
| EPT. | epipterygoid |
| ET. | "excavatio tympanica" |
| FACT. | restored facet on paroccipital process for tabular |
| FM. | foramen magnum |
| FO. | fenestra ovalis |
| FPQ. | paraquadrate foramen |
| FPQA. | accessory paraquadrate foramen |
| FR. | frontal |
| G. | groove in stapes for vena capitis lateralis |
| IOV. | interorbital anastomotic vein |
| IT. | intertemporal |
| JU. | jugal |
| L. | lacrimal |
| MX. | maxilla |
| NA. | nasal |
| OEPT. | otic process of epipterygoid |
| P. | parietal |
| PA. | prearticular |
| PAG. | groove for palatine artery and nerve |
| PAL. | palatine |
| PAS. | parasphenoid |
| PF. | foramen for parietal organ |
| PIT. | pituitary fossa |
| PMX. | premaxilla |
| PO. | postorbital |
| POF. | postfrontal |
| POP. | paroccipital process |
| POPC. | cartilaginous region of paroccipital process |
| PP. | postparietal (dermal supraoccipital) |
| PRF. | prefrontal |
| PT. | pterygoid |
| PTF. | posttemporal fossa |
| PTFOR. | posttemporal foramen |
| Q. | quadrate |
| QJ. | quadratojugal |
| SANG. | surangular |
| SE. | sphenethmoid |
| SMX. | septomaxilla |
| SOCC. | supraoccipital cartilage |
| SP. | anterior splenial |
| SPP. | posterior splenial |
| SQ. | squamosal |
| ST. | supratemporal |
| STP. | stapes |
| STPF. | stapedial foramen |
| T. | tabular |
| TFAC. | facet on tabular for paroccipital process |
| VN. | presumed venous foramina |
| VO. | vomer |

Nerve exits are indicated by roman numerals

# STRUCTURE OF LITTLE NORTH MOUNTAIN OF THE NORTH-CENTRAL APPALACHIANS

ALBERT W. GILES
University of Arkansas[1]

## ABSTRACT

Little North Mountain is a low range extending through northwestern Virginia and West Virginia into Maryland, bounding the Shenandoah Valley on the west. A former investigation of the geology of the range in northwestern Virginia led the writer to interpret its structure as a faulted monocline bounded by overthrusts with southeastward inclination. The major overthrust was considered to present a continuous trace on the west side of the range. The other faults were believed to be distributive from the major overthrust, their traces located generally east of the mountain crest. Butts and Edmundson have recently interpreted the structure of Little North Mountain as the northwestern limb of an overturned and faulted anticline from which the opposing and overthrust limb has been removed by erosion. They fail to identify the postulated overthrust on the west side of the range. The range throughout its extent in northwestern Virginia is characterized by irregular distribution of its formations. These features were formerly interpreted as due to faulting, but, according to Butts and Edmundson, they result from unequal sedimentation in a littoral environment. A comparison of the description of the stratigraphic and structural features of Little North Mountain by Butts and Edmundson with the results of earlier studies indicates that their interpretation of the structure of Little North Mountain as a faulted anticline is not inconsistent with available evidence. They fail completely, however, to present adequate and convincing evidence substantiating their interpretation of the stratigraphic peculiarities characteristic of Little North Mountain as due to depositional, rather than structural, causes.

## INTRODUCTION[2]

Little North Mountain is a low mountain range extending from the north-central part of Rockbridge County in western Virginia northeastward through West Virginia into northern Maryland, where it terminates in Bear Pond Mountains (Fig. 1). In Virginia the range traverses northern Rockbridge, Augusta, Rockingham, Shenandoah, and Frederick counties, passes through Berkeley County, West Virginia, and enters Washington County, Maryland. In West Virginia and Maryland it is known as "North Mountain." The total length of the range is about 150 miles, of which approximately 125 miles are in Virginia. The range is not lofty, averaging

[1] Research Paper No. 758 ("Journal Series"), University of Arkansas.

[2] The writer is indebted to Mr. George W. Stose, of the U.S. Geological Survey, for criticism of the manuscript and for suggestions designed to bring the interpretation of the structure of Little North Mountain in Virginia in accord with that of North Mountain in West Virginia and Maryland.

not more than 600–800 feet above its surroundings in northern Virginia, West Virginia, and Maryland. Farther south, in northern Shenandoah County, its height above the adjacent lowlands is 900–1,200 feet, but in southern Shenandoah and in northern Rockingham

FIG. 1.—Index map showing course of Little North Mountain in Virginia and adjacent states and the numerous gaps interrupting its trend.

counties its crest descends to a few hundred feet above the valleys on either side. It is scarcely more imposing in northern Augusta County, but in southern Augusta and northern Rockbridge counties it rises 1,000–1,500 feet above the neighboring lowlands, the highest part of its entire length. Throughout its extent the range is interrupted by numerous gaps, some of which are distinctly water gaps; other gaps have a width of several miles. In central Frederick Coun-

ty and southern Shenandoah County it is scarcely a distinct range, and it is essentially absent in southern Rockingham and northern Augusta counties. Throughout its extent Little North Mountain is the easternmost range of the Appalachian Ridge and Valley province, making the western boundary of the Shenandoah Valley. Much of the range is wooded.

## LITERATURE

The northern part of Little North Mountain has been mapped and described by several investigators in recent years. A part of the range in West Virginia has been described by G. W. Stose and C. K. Swartz,[3] and the entire range in West Virginia is mapped and described by G. P. Grimsley.[4] The stratigraphy and structure of North Mountain of Maryland are mapped and described by R. S. Bassler[5] and by C. K. Swartz.[6] The geology of Little North Mountain in northern Virginia has been described by Albert W. Giles.[7] Recently the geology of the mountain range in northern Virginia has again been described by C. Butts and R. S. Edmundson[8] and by Edmundson.[9]

## STRATIGRAPHY

Eight formations comprise Little North Mountain in northern Virginia, ranging from Upper Ordovician to Middle Devonian and having a total maximum thickness of about 1,800 feet (Table 1). The Martinsburg shale of Middle and Upper Ordovician age has a nearly continuous outcrop east of the range, and the outcrop of the Marcellus shale of Middle Devonian age parallels the mountain range on the west.

[3] "Pawpaw-Hancock Folio No. 179," *Geologic Atlas of the United States* (U.S. Geol. Surv., 1912).

[4] "Jefferson, Berkeley and Morgan Counties, West Virginia," *Rept. W.Va. Geol. Surv.* (1916).

[5] "Cambrian and Ordovician Deposits of Maryland," *Rept. Md. Geol. Surv.* (1919).

[6] "Silurian of Maryland," *Rept. Md. Geol. Surv.* (1923).

[7] "The Geology of Little North Mountain in Northern Virginia and West Virginia," *Jour. Geol.*, Vol. XXV (1927), pp. 32–57.

[8] "Geology of Little North Mountain in Northern Virginia," *Va. Geol. Surv. Bull. 51* (1939), pp. 165–79.

[9] "Origin of Little North Mountain in Northern Virginia," *Jour. Geol.*, Vol. LXVIII (1940), pp. 532–52.

The Tuscarora (Clinch) sandstone forms the backbone of Little North Mountain. This resistant sandstone is the chief ridge-maker of the central Appalachians, forming long ridges, the continuity of which may be interrupted by narrow water gaps and by gaps several miles wide where the sandstone has been greatly thinned or removed by faulting.

TABLE 1

FORMATIONS INVOLVED IN THE STRUCTURE OF LITTLE NORTH MOUNTAIN AND ADJACENT AREAS IN NORTHERN VIRGINIA*

| System | Formation | | Maximum Thickness (Feet) |
|---|---|---|---|
| Devonian | Hamilton formation | "Romney" shale | 1,000 |
| | Marcellus shale† | | 500 |
| | Onondaga shale‡ | | 200 |
| | Oriskany sandstone‡ | | 100 |
| | Helderberg limestone‡ | | 300 |
| Silurian | Cayugan group‡ | | 400 |
| | Clinton formation‡ | | 200 |
| | Tuscarora sandstone‡ | | 300 |
| Ordovician | Juniata formation‡ | | 100 |
| | Oswego sandstone‡ | | 200 |
| | Martinsburg shale§ | | 2,000 |
| | Chambersburg limestone | | 600 |
| | Lenoir limestone | | 50 |
| | Mosheim limestone | | 50 |
| | Beekmantown limestone | | 2,500 |
| | Chapultepec limestone | | 600 |
| Cambrian | Conococheague limestone | | 2,000 |
| | Elbrook limestone | | 2,000 |

* Succession and thickness after Butts and Edmundson.
† Outcrop is adjacent to Little North Mountain on the west.
‡ Formations included in Little North Mountain.
§ Outcrop is adjacent to Little North Mountain on the east.

## GENERAL STRUCTURE

Structurally Little North Mountain is a monocline consisting of overturned beds with a steep southeastward dip averaging roughly 60°. On the east side the monocline is bounded by overthrust Cambrian and Ordovician strata with steep eastward dips, and on the west by a broad syncline consisting of Devonian strata. The eastern limb of the Devonian syncline is overturned and dips steeply east-

ward.[10] According to Edmundson, Little North Mountain is a "structural entity."[11]

The regional structure affords ample evidence of intense compression from the southeast. The steep regional dip and the overthrusts with large throw and steep southeastward inclination reflect the intense compression. The formations have been thinned, their strata frequently slickensided; and weaker beds in the succession show repeated folding. The formations, particularly on the western flank of the mountain, exhibit marked variations in thickness within short distances and are absent in places, so that their distribution is distinctly lenticular (Fig. 3).

Giles has interpreted the structure of Little North Mountain in northern Virginia as follows:

> Structurally Little North Mountain may be considered a faulted monocline of overturned beds with steep southeastward dip bounded on the east by closely compressed generally overturned folds affecting the Cambrian and Ordovician formations underlying the Valley, and on the west by a broad syncline developed in Devonian rocks. The faults are overthrusts from the southeast with southeastward inclination. The major overthrust presents a continuous trace on the west side of the mountain. The other faults are distributive from the major overthrust and consequently are discontinuous, merging with the major overthrust at infrequent intervals. Their traces in general lie east of the mountain crest and locally may depart some distance beyond the foot of the mountain. Rarely are more than three faults with the significant displacement present, and for much of the distance the displacement is limited to two fault surfaces.[12]

This interpretation of the structure of Little North Mountain agrees with the interpretation of its structure in West Virginia by Grimsley and by Stose and Swartz and in Maryland by Swartz and by Bassler, except that they regard the major overthrust as lying east of the mountain, the others being distributive from it.

Butts and Edmundson accept only a part of this interpretation of the structure. They agree that "the overturned beds, with steep southeast dips bounded on the east by faulted overturned Cambrian and Ordovician rocks and on the west by a broad Devonian syncline,

[10] Stose and Swartz, *op. cit.*, p. 17, Fig. 7; Grimsley, *op. cit.*, Fig. 16, facing p. 120; Giles, *op. cit.*, pp. 54–55, Figs. 4 and 5; Butts and Edmundson, *op. cit.*, Pl. 23; Edmundson, *op. cit.*, p. 546, Fig. 6.

[11] Edmundson, *op. cit.*, p. 535.

[12] Giles, *op. cit.*, p. 53.

are well displayed; but the assumed major overthrust, with a continuous trace on the west side of the mountain, was not identified."[13] They attribute the marked variation in thickness and lenslike distribution of the formations composing Little North Mountain to be due to "discontinuous sedimentation, rather than faulting,"[14] although "it is not to be denied that some displacement along certain zones of weakness, where deposition was slight, could have been a contributing factor in producing the present structures. Such an allied factor is indicated at a few places along the mountain."[15]

Butts and Edmundson have attempted to picture the environment in which the structural features of Little North Mountain have been produced as follows:

> The writers find it difficult to reconstruct the sedimentary environment, but it appears most reasonable to assume that the shallow seas from Upper Ordovician to Lower Devonian, inclusive, locally were fringed with low islands, peninsulas, straits, lagoons, and other near-shore surface features. One or more of these geographic conditions, in conjunction with oscillations of the seas and fluctuations in sedimentation, are believed to have caused the marked variations in the thickness of the formations and the stratigraphic discontinuities along Little North Mountain.[16]

## EVALUATION OF GENERAL STRUCTURAL EVIDENCE

Not only do the conclusions presented by Butts and Edmundson regarding the structure of Little North Mountain differ radically from the conclusions previously obtained, but their explanation of the structural features of Little North Mountain which have long been known is both inadequate and unsatisfactory.

Although the intensity of the compression involved in Appalachian structure has been recognized for more than a century, Butts and Edmundson have apparently failed to appreciate its significance in producing the structure of Little North Mountain. Their failure to recognize the effects of compression is illustrated in their cross sections of the structure of the region. They estimate the maximum thickness of the Martinsburg shale in northern Virginia to be 2,000 feet, which is represented in their cross sections as part of the eastern limb of the Devonian syncline, which terminates eastward in a low-

[13] Edmundson, *op. cit.*, p. 534.

[14] *Ibid.*

[15] Butts and Edmundson, *op. cit.*, p. 179.

[16] *Ibid.*

angle overthrust named the "Little North Mountain fault." Measurements of the thickness of the Martinsburg as represented in their cross sections give thickness much greater than 2,000 feet. In sections *EE'* the thickness represented is 2,900 feet;[17] in section *FF'*, 2,500 feet; in section *II'*, 3,300 feet; and in section *JJ'*, 3,900 feet. In all these sections the Martinsburg is represented as terminating eastward in a thrust fault, so that the thicknesses just cited do not represent the total thickness of the formation. Earlier measurements indicate that in northern Virginia the Martinsburg is about 2,000 feet thick. The formation thickens northward to about 2,500 feet in Maryland and southern Pennsylvania. The excessive width of outcrop of the Martinsburg throughout this area implies repeated folding of the weak beds comprising the formation.[18] The cross sections drawn by Butts and Edmundson present no suggestion of repeated folding of the weak shale, although such folding was long ago recognized and must be inferred since the shale was compressed against the strong Tuscarora sandstone on the west by the equally strong and thick Ordovician limestones on the east.

In assuming that oscillation of the sea and fluctuations in "nearshore" sedimentation have been the cause of the lenticular distribution of formations and stratigraphic discontinuities along Little North Mountain, these authors are apparently trying to picture a littoral environment in which the sediments were deposited. Littoral deposits have certain distinctive features facilitating their recognition. They are thin and discontinuous lenses of muds, clays, sands, and gravels with rapid variations in initial dips, cross-bedding, and rapid and abrupt changes in type of sediments laterally and vertically. The surfaces of numerous beds preserve ripple and wave marks, sun cracks, and rain prints. Repetition within short vertical intervals of unconformities with basal conglomerates and repeated overlap and offlap are also characteristic of littoral deposits.

These features are generally absent from the formations in the Little North Mountain stratigraphic succession, ranging from Upper Ordovician to Middle Devonian. The Tuscarora and Oriskany sandstones exhibit shore phases, but their wide distribution in eastern United States demonstrates conclusively that these sandstones

[17] *Ibid.*, Pl. 23.

[18] Giles, *op. cit.*, Figs. 4 and 5.

are essentially offshore deposits. The Juniata formation is generally interpreted as nonmarine in origin; but the Martinsburg shale, Clinton and Cayugan shales and limestones, Helderberg limestone, and Onondaga limestone and shale are typical offshore deposits, widespread throughout the Appalachian region and eastern interior. If the widely distributed formations represented in Little North Mountain are to be interpreted as littoral deposits, then most of the formations comprising the Paleozoic section of eastern North America may likewise be interpreted as littoral deposits. The fact that the formations involved are recognized throughout the Appalachian region and much of the eastern interior and can be traced as continuous units with uniform lithology for hundreds of miles, except where faulted out locally, is wholly incompatible with the interpretation by Butts and Edmundson of the environmental conditions governing the deposition of the formations. Since the formations are typical offshore deposits, the general continuity they exhibit is to be expected. Why they should be so discontinuous in northern Virginia and elsewhere so continuous must rest upon factors other than discontinuous deposition. As has long been known, the stratigraphic succession from the Middle Ordovician to the Middle Devonian of the central Appalachians includes several unconformities; but these erosional intervals, like the overlaps and offlaps, are regional in extent rather than the local characteristics of littoral deposits. The stratigraphic features of the formations of the Little North Mountain section fail to support, in any respect, the littoral sedimentary environment pictured by Butts and Edmundson, which they have found "difficult to reconstruct."

## DETAILED STRUCTURE

The distance traversed by Little North Mountain across Frederick County, Virginia, is approximately 20 miles (Fig. 2). The areal sectional maps of Figure 3 illustrate the distribution of formations comprising Little North Mountain in Frederick County. The sectional maps have been taken directly from the map prepared by Butts and Edmundson[19] and were selected where the stratigraphic discontinu-

[19] Butts and Edmundson, *op. cit.*, Pl. 23.

ities marking the trend of Little North Mountain are well displayed. Their combined length is approximately 16 miles.

Map *A*, Figure 3, illustrates the distribution of formations in the vicinity of Green Springs $2\frac{1}{2}$ miles south of the Virginia–West Virginia boundary. The structure at Green Springs was interpreted by

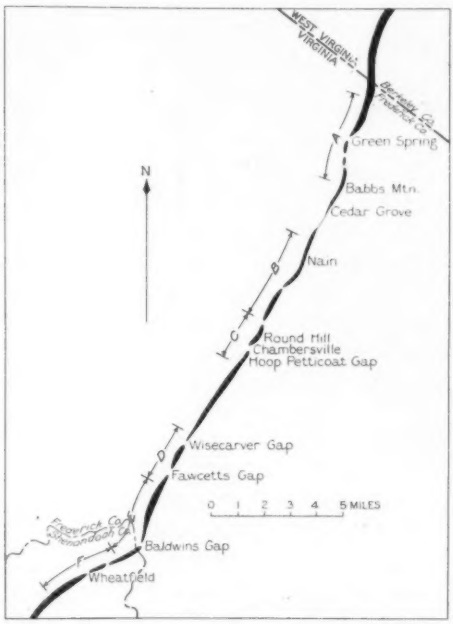


FIG. 2.—Course of Little North Mountain across Frederick County in northern Virginia showing the numerous gaps and location of sectional maps illustrated in Figure 3.

Giles[20] as due to faulting which cut out part of the Tuscarora, all the Clinton and Cayugan, and nearly all the Helderberg. A short distance south of Green Springs the Tuscarora is absent, the Martinsburg lying against the Lower Devonian, with all the Silurian gone. One-half mile farther south the Lower Devonian has disappeared, and the Martinsburg lies against the Onondaga shale. Butts and

[20] Giles, *op. cit.*, Fig. 4, cross section 6.

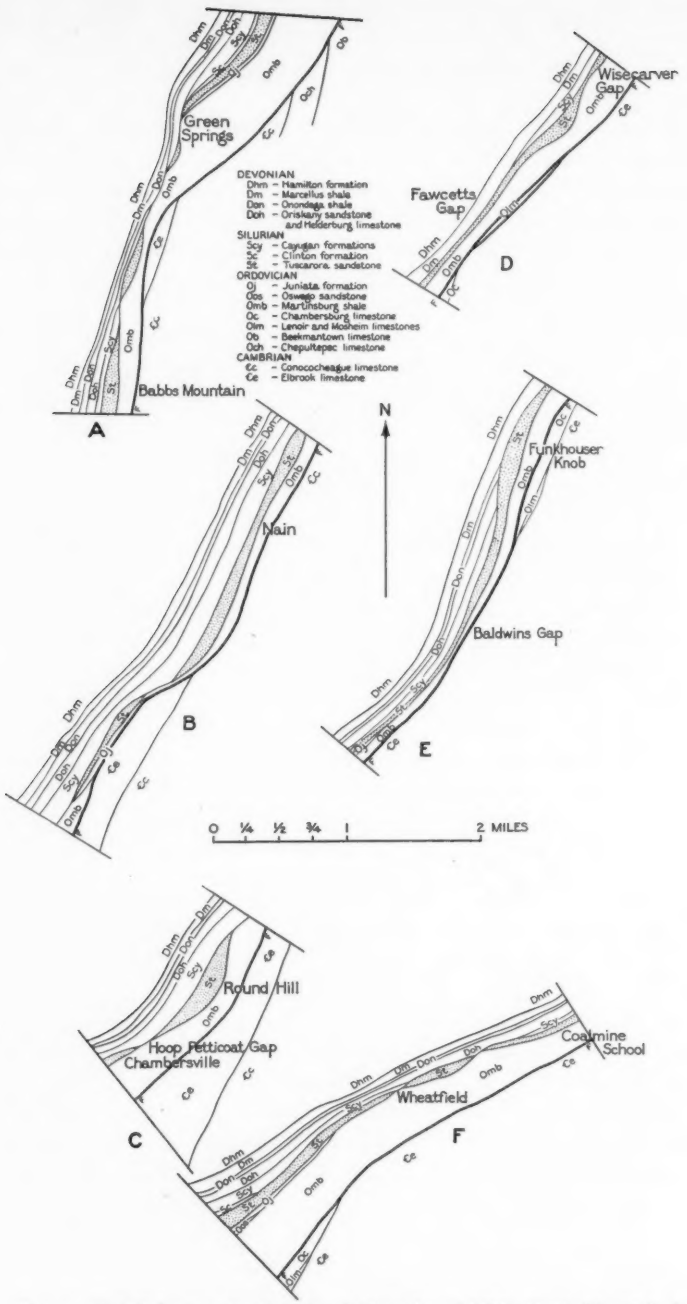


FIG. 3.—Detailed maps showing the stratigraphy of Little North Mountain in northern Virginia. Based on mapping by Butts and Edmundson.

Edmundson describe the structural features in the vicinity of Green Springs as follows:

> The Silurian formations diminish in thickness from the Virginia boundary to a point just north of the gap west of Green Springs. Here the Juniata, Tuscarora, Clinton and Cayugan sandstones and shales show a rather sharp flexure to the southeast and apparently end abruptly against the underlying Martinsburg shale. It is reasonably certain that a minor fault, in conjunction with pronounced thinning, must be postulated to explain the distribution of the formations at this locality. This oblique fault apparently extends to the southwest for about 2 miles and dies out as a strike fault along the northeastern slope of Babbs Mountain. Through the Green Springs water gap the overturned formations in ascending order are Martinsburg, Helderberg-Oriskany, Onondaga Marcellus, and Hamilton.[21]

Apparently, Butts and Edmundson recognize faulting as the fundamental cause of the structure illustrated in Map *A*, Figure 3.

The map of the geology in the vicinity of Nain, 5 miles south of Green Springs, illustrates the rapid thinning and thickening of the Tuscarora, as well as its deletion within short distances (Fig. 3, Map *B*). The width of outcrop of the Cayugan is equally variable. The Clinton is absent. According to Butts and Edmundson, the Clinton is absent "for about 20 miles" from the vicinity of Green Springs to the southern part of Frederick County. About 1 mile south of Nain the Tuscarora disappears, the Martinsburg lying against Cayugan. In describing the structure at this locality Butts and Edmundson state that "it is not impossible that compression at this place or relative weakness, due to thinning of the Tuscarora, may have resulted in minor faulting, but the lack of any noticeable distortion in the associated beds rather favors a sedimentary unconformity."[22]

About 8 miles south of Green Springs at Round Hill a similar structure is mapped by Butts and Edmundson (Fig. 3, Map *C*). North of Round Hill the Tuscarora and Clinton are missing, bringing the Martinsburg against the Cayugan. South of Round Hill at Chambersville the Tuscarora and Clinton are again missing, the Martinsburg lying against the Cayugan. The cross section through Chambersville is illustrated by Giles.[23] Here Butts and Edmundson identify the Clinton as Cayugan and interpret the structure as follows: "The thinning and omission of the Tuscarora sandstone near

[21] Butts and Edmundson, *op. cit.*, p. 175.

[22] *Ibid.* [23] Giles, *op. cit.*, Fig. 5, cross section 9.

and in Hoop Petticoat Gap may be due in part to some local readjustment in the weak zone, but the important structural feature is believed to be directly connected with primary deposition."[24]

Round Hill is described as follows:

> Along the northeast slope of Round Hill the Tuscarora begins as a thin formation, rapidly increases to a maximum thickness of about 250 feet near the summit, and then gradually thins out at Hoop Petticoat Gap, west of Chambersville along U.S. Route 50. To interpret this feature as a depositional lens seems highly speculative, yet an original local basin of deposition with an initial dip of about 5 degrees would probably explain it.[25]

About $4\frac{1}{2}$ miles south of Chambersville is Wisecarver Gap, and $1\frac{1}{2}$ miles farther south Little North Mountain is again interrupted by Fawcetts Gap (Fig. 3, Map *D*). The section through Wisecarver Gap "is noteworthy because of the absence of the Helderberg limestones and Onondaga shale."[26] The section through Fawcetts Gap includes but 5 feet of Tuscarora bounded on the east by the Martinsburg shale and on the west by the Marcellus shale. A cross section through the gap has been illustrated by Giles.[27]

Describing the structure section through Fawcetts Gap, Butts and Edmundson state:

> The absence particularly of the Cayugan, Helderberg-Oriskany, and Onondaga formations make this section unique for the part of Little North Mountain discussed in this paper. The explanation of this phenomenon may be a matter of some conjecture, but the lack of any apparent distortion, such as drag folding and brecciation of the associated beds, and the observed gradual diminution in thickness and final disappearance of the formations north of Fawcetts Gap suggest some depositional and erosional causes rather than faulting. It should be emphasized that *the entire Silurian System is represented at this locality by a total thickness of 5 feet.*[28]

The section has also been photographed by Bevan showing the thin Tuscarora lying against the Marcellus with Clinton, Cayugan, Helderberg, Oriskany, and Onondaga formations absent, although no fault is recognized.[29]

About 1 mile southwest of Fawcetts Gap the Tuscarora sandstone thickens and forms Funkhouser Knob with section "similar [to that]

[24] Butts and Edmundson, *op. cit.*, p. 176. [25] *Ibid.* [26] *Ibid.*

[27] Giles, *op. cit.*, Fig. 5, cross section 11.

[28] Butts and Edmundson, *op. cit.*, p. 177. [29] Edmundson, *op. cit.*, p. 538, Fig. 3, *C*.

of Fawcetts Gap, except for the thickened Tuscarora," according to Butts and Edmundson. Between the gap and the knob the Tuscarora is mapped by them as a thin but continuous formation, "but it is possible instead that it occurs in a series of thin lenses."[30]

On the southwest side of Funkhouser Knob the Cayugan, Helderberg, Oriskany, and Onondaga terminate successively against the Tuscarora of the knob (Fig. 3, Map *E*). This relationship is described by Butts and Edmundson as an overlap.[31] According to this interpretation, four formations ranging from the Middle Silurian into the Middle Devonian, having an aggregate thickness of 1,000 feet, overlap and disappear within a distance of less than 1 mile. If this interpretation is correct, it is a very unusual and remarkable example of overlap. Butts and Edmundson have prepared a cross section through Funkhouser Knob,[32] and Giles one through Baldwins Gap, a mile farther south.[33] In the latter section the Cayugan is represented in contact with the Romney; but, according to Butts and Edmundson, the sequence is Cayugan, Helderberg, and Onondaga (Romney) with no Oriskany.

Two and one-half miles southwest of Baldwins Gap is Wheatfield, lying in another gap of Little North Mountain (Fig. 3, Map *F*). Here the Tuscarora is absent. Three-fourths of a mile northeast of Wheatfield the Tuscarora is again absent, a thin lens of Tuscarora intervening between two gaps. West of Wheatfield the Clinton is absent, and the Cayugan terminates northward against the intervening lens, to be resumed again north of the next gap. In this gap "the Martinsburg shale is adjacent to Helderberg limestone without any visible evidence of brecciation, drag folding, or other structural features which would suggest faulting." In fact, "discontinuous outcrops of several formations are the rule between the gap east of Coalmine School and Wheatfield."[34]

South of Wheatfield, continuing into Shenandoah County, all the formations above the Tuscarora are present, according to Butts and Edmundson, although the "section is not continuously exposed."

[30] Butts and Edmundson, *op. cit.*, p. 177.

[31] *Ibid.*

[32] *Ibid.*, Pl. 23, cross section *GG'*.

[33] Giles, *op. cit.*, Fig. 5, cross section 12.

[34] Butts and Edmundson, *op. cit.*, p. 178.

EVALUATION OF DETAILED STRUCTURAL EVIDENCE

As is well known, the stratigraphic evidence suggesting faulting consists essentially of discontinuity of linear outcrops along the strike of the supposed fault, repetition of the same beds and abrupt termination of formations along the strike, and omission of formations which are part of the normal stratigraphic sequence of the region. These criteria are universally used in the interpretation of Appalachian structure and the recognition of faults. The application of these criteria leads to the conclusion that faulting along the west side of Little North Mountain most satisfactorily explains the distribution of the formations involved in the uplift. It would be difficult to find a locality of similar area where discontinuity of linear outcrops, abrupt termination of formations along the strike, and repeated omission of formations are better displayed than along the western side of Little North Mountain. These structural features are well illustrated in the map prepared by Butts and Edmundson showing the geology of Little North Mountain,[35] which has been used as the basis for the sectional maps of Figure 3.

Although the interpretation by Butts and Edmundson of the areal distribution and thinning of formations composing Little North Mountain is contrary to the generally accepted principles used in interpreting structure, their proposed explanation of the structure suffers further by the adoption of different explanations for similar areal relationships exhibited by the formations. They interpret the structure in the vicinity of Green Springs as due to faulting (Fig. 3, Map *A*). South of Nain the juxtaposition of the Martinsburg and Cayugan may have resulted from "minor faulting,"[36] although a "sedimentary unconformity" is favored (Map *B*). Near Chambersville the "thinning and omission of the Tuscarora sandstone near and in Hoop Petticoat Gap may be due in part to some local readjustment in the weak zone, but the important structural feature is believed to be directly connected with primary deposition" (Map *C*). The interpretation of the Tuscarora at Round Hill as a depositional lens "seems highly speculative" but is nevertheless favored by them (Map *C*). The deletion of all the Silurian but 5 feet of Tuscarora at Fawcetts Gap is regarded by Butts and Edmundson as "unique,"

[35] *Ibid.*, Pl. 23. [36] *Ibid.*, p. 175.

and "the explanation of this phenomenon may be a matter of some conjecture" (Map *D*). Nevertheless, it is suggested to be due to "depositional and erosional causes rather than faulting." The abrupt termination against Funkhouser Knob of the Upper Silurian and Lower Devonian formations with a maximum thickness of 1,000 feet is ascribed to overlap by Butts and Edmundson (Map *E*). "The discontinuous outcrops of several formations" between Wheatfield and Coalmine School and the juxtaposition of Martinsburg shale and Helderberg limestone with all the Silurian formations missing do not "suggest faulting" to Butts and Edmundson, although all the Silurian formations are present 1½ miles south of Wheatfield according to their mapping (Fig. 3, Map *F*).

The evidence presented by Butts and Edmundson to account for the lenticular distributions of formations of Little North Mountain as due to irregularities of deposition rather than to faulting is both inadequate and unconvincing. The similarity of the structure along the western flank of Little North Mountain demonstrates the operation of a single cause in its origin; yet Butts and Edmundson employ different explanations to account for similar structures. Faulting, the most obvious explanation, is avoided. Why faulting, which would seem to be the rational explanation of the phenomena described by Butts and Edmundson, is so rigidly excluded by them is not obvious, and they offer no valid evidence that faulting is not the cause of the irregular distribution of the formations.

The structure of Little North Mountain in northern Virginia may be illustrated by the section through Fawcetts Gap, as interpreted in Figure 4. The trace of the main overthrust lies east of the mountain crest. A parallel overthrust trends northeastward west of the mountain crest. The latter is an auxiliary of the main overthrust. In the vicinity of Fawcetts Gap the main overthrust is a double fault. According to this interpretation of its structure, Little North Mountain may be regarded as an anticline overturned toward the west and broken and thrust over the edge of the syncline. This interpretation agrees with the interpretation of the structure of North Mountain in West Virginia proposed by Stose and Swartz.[37] Edmundson also regards the structure of Little North Mountain as an overturned and

[37] *Op. cit.*, p. 17, Fig. 7.

The Tuscarora (Clinch) sandstone forms the backbone of Little North Mountain. This resistant sandstone is the chief ridge-maker of the central Appalachians, forming long ridges, the continuity of which may be interrupted by narrow water gaps and by gaps several miles wide where the sandstone has been greatly thinned or removed by faulting.

TABLE 1

FORMATIONS INVOLVED IN THE STRUCTURE OF LITTLE NORTH MOUNTAIN AND ADJACENT AREAS IN NORTHERN VIRGINIA*

| System | Formation | Maximum Thickness (Feet) |
|---|---|---|
| Devonian | Hamilton formation | 1,000 |
| | Marcellus shale† } "Romney" shale | 500 |
| | Onondaga shale‡ } | 200 |
| | Oriskany sandstone‡ | 100 |
| | Helderberg limestone‡ | 300 |
| Silurian | Cayugan group‡ | 400 |
| | Clinton formation‡ | 200 |
| | Tuscarora sandstone‡ | 300 |
| Ordovician | Juniata formation‡ | 100 |
| | Oswego sandstone‡ | 200 |
| | Martinsburg shale§ | 2,000 |
| | Chambersburg limestone | 600 |
| | Lenoir limestone | 50 |
| | Mosheim limestone | 50 |
| | Beekmantown limestone | 2,500 |
| | Chapultepec limestone | 600 |
| Cambrian | Conococheague limestone | 2,000 |
| | Elbrook limestone | 2,000 |

* Succession and thickness after Butts and Edmundson.
† Outcrop is adjacent to Little North Mountain on the west.
‡ Formations included in Little North Mountain.
§ Outcrop is adjacent to Little North Mountain on the east.

## GENERAL STRUCTURE

Structurally Little North Mountain is a monocline consisting of overturned beds with a steep southeastward dip averaging roughly 60°. On the east side the monocline is bounded by overthrust Cambrian and Ordovician strata with steep eastward dips, and on the west by a broad syncline consisting of Devonian strata. The eastern limb of the Devonian syncline is overturned and dips steeply east-

ward.[10] According to Edmundson, Little North Mountain is a "structural entity."[11]

The regional structure affords ample evidence of intense compression from the southeast. The steep regional dip and the overthrusts with large throw and steep southeastward inclination reflect the intense compression. The formations have been thinned, their strata frequently slickensided; and weaker beds in the succession show repeated folding. The formations, particularly on the western flank of the mountain, exhibit marked variations in thickness within short distances and are absent in places, so that their distribution is distinctly lenticular (Fig. 3).

Giles has interpreted the structure of Little North Mountain in northern Virginia as follows:

> Structurally Little North Mountain may be considered a faulted monocline of overturned beds with steep southeastward dip bounded on the east by closely compressed generally overturned folds affecting the Cambrian and Ordovician formations underlying the Valley, and on the west by a broad syncline developed in Devonian rocks. The faults are overthrusts from the southeast with southeastward inclination. The major overthrust presents a continuous trace on the west side of the mountain. The other faults are distributive from the major overthrust and consequently are discontinuous, merging with the major overthrust at infrequent intervals. Their traces in general lie east of the mountain crest and locally may depart some distance beyond the foot of the mountain. Rarely are more than three faults with the significant displacement present, and for much of the distance the displacement is limited to two fault surfaces.[12]

This interpretation of the structure of Little North Mountain agrees with the interpretation of its structure in West Virginia by Grimsley and by Stose and Swartz and in Maryland by Swartz and by Bassler, except that they regard the major overthrust as lying east of the mountain, the others being distributive from it.

Butts and Edmundson accept only a part of this interpretation of the structure. They agree that "the overturned beds, with steep southeast dips bounded on the east by faulted overturned Cambrian and Ordovician rocks and on the west by a broad Devonian syncline,

[10] Stose and Swartz, *op. cit.*, p. 17, Fig. 7; Grimsley, *op. cit.*, Fig. 16, facing p. 120; Giles, *op. cit.*, pp. 54–55, Figs. 4 and 5; Butts and Edmundson, *op. cit.*, Pl. 23; Edmundson, *op. cit.*, p. 546, Fig. 6.

[11] Edmundson, *op. cit.*, p. 535.

[12] Giles, *op. cit.*, p. 53.

are well displayed; but the assumed major overthrust, with a continuous trace on the west side of the mountain, was not identified."[13] They attribute the marked variation in thickness and lenslike distribution of the formations composing Little North Mountain to be due to "discontinuous sedimentation, rather than faulting,"[14] although "it is not to be denied that some displacement along certain zones of weakness, where deposition was slight, could have been a contributing factor in producing the present structures. Such an allied factor is indicated at a few places along the mountain."[15]

Butts and Edmundson have attempted to picture the environment in which the structural features of Little North Mountain have been produced as follows:

> The writers find it difficult to reconstruct the sedimentary environment, but it appears most reasonable to assume that the shallow seas from Upper Ordovician to Lower Devonian, inclusive, locally were fringed with low islands, peninsulas, straits, lagoons, and other near-shore surface features. One or more of these geographic conditions, in conjunction with oscillations of the seas and fluctuations in sedimentation, are believed to have caused the marked variations in the thickness of the formations and the stratigraphic discontinuities along Little North Mountain.[16]

## EVALUATION OF GENERAL STRUCTURAL EVIDENCE

Not only do the conclusions presented by Butts and Edmundson regarding the structure of Little North Mountain differ radically from the conclusions previously obtained, but their explanation of the structural features of Little North Mountain which have long been known is both inadequate and unsatisfactory.

Although the intensity of the compression involved in Appalachian structure has been recognized for more than a century, Butts and Edmundson have apparently failed to appreciate its significance in producing the structure of Little North Mountain. Their failure to recognize the effects of compression is illustrated in their cross sections of the structure of the region. They estimate the maximum thickness of the Martinsburg shale in northern Virginia to be 2,000 feet, which is represented in their cross sections as part of the eastern limb of the Devonian syncline, which terminates eastward in a low-

[13] Edmundson, *op. cit.*, p. 534.

[14] *Ibid.*

[15] Butts and Edmundson, *op. cit.*, p. 179.

[16] *Ibid.*

angle overthrust named the "Little North Mountain fault." Measurements of the thickness of the Martinsburg as represented in their cross sections give thickness much greater than 2,000 feet. In sections *EE'* the thickness represented is 2,900 feet;[17] in section *FF'*, 2,500 feet; in section *II'*, 3,300 feet; and in section *JJ'*, 3,900 feet. In all these sections the Martinsburg is represented as terminating eastward in a thrust fault, so that the thicknesses just cited do not represent the total thickness of the formation. Earlier measurements indicate that in northern Virginia the Martinsburg is about 2,000 feet thick. The formation thickens northward to about 2,500 feet in Maryland and southern Pennsylvania. The excessive width of outcrop of the Martinsburg throughout this area implies repeated folding of the weak beds comprising the formation.[18] The cross sections drawn by Butts and Edmundson present no suggestion of repeated folding of the weak shale, although such folding was long ago recognized and must be inferred since the shale was compressed against the strong Tuscarora sandstone on the west by the equally strong and thick Ordovician limestones on the east.

In assuming that oscillation of the sea and fluctuations in "nearshore" sedimentation have been the cause of the lenticular distribution of formations and stratigraphic discontinuities along Little North Mountain, these authors are apparently trying to picture a littoral environment in which the sediments were deposited. Littoral deposits have certain distinctive features facilitating their recognition. They are thin and discontinuous lenses of muds, clays, sands, and gravels with rapid variations in initial dips, cross-bedding, and rapid and abrupt changes in type of sediments laterally and vertically. The surfaces of numerous beds preserve ripple and wave marks, sun cracks, and rain prints. Repetition within short vertical intervals of unconformities with basal conglomerates and repeated overlap and offlap are also characteristic of littoral deposits.

These features are generally absent from the formations in the Little North Mountain stratigraphic succession, ranging from Upper Ordovician to Middle Devonian. The Tuscarora and Oriskany sandstones exhibit shore phases, but their wide distribution in eastern United States demonstrates conclusively that these sandstones

[17] *Ibid.*, Pl. 23.

[18] Giles, *op. cit.*, Figs. 4 and 5.

are essentially offshore deposits. The Juniata formation is generally interpreted as nonmarine in origin; but the Martinsburg shale, Clinton and Cayugan shales and limestones, Helderberg limestone, and Onondaga limestone and shale are typical offshore deposits, widespread throughout the Appalachian region and eastern interior. If the widely distributed formations represented in Little North Mountain are to be interpreted as littoral deposits, then most of the formations comprising the Paleozoic section of eastern North America may likewise be interpreted as littoral deposits. The fact that the formations involved are recognized throughout the Appalachian region and much of the eastern interior and can be traced as continuous units with uniform lithology for hundreds of miles, except where faulted out locally, is wholly incompatible with the interpretation by Butts and Edmundson of the environmental conditions governing the deposition of the formations. Since the formations are typical offshore deposits, the general continuity they exhibit is to be expected. Why they should be so discontinuous in northern Virginia and elsewhere so continuous must rest upon factors other than discontinuous deposition. As has long been known, the stratigraphic succession from the Middle Ordovician to the Middle Devonian of the central Appalachians includes several unconformities; but these erosional intervals, like the overlaps and offlaps, are regional in extent rather than the local characteristics of littoral deposits. The stratigraphic features of the formations of the Little North Mountain section fail to support, in any respect, the littoral sedimentary environment pictured by Butts and Edmundson, which they have found "difficult to reconstruct."

## DETAILED STRUCTURE

The distance traversed by Little North Mountain across Frederick County, Virginia, is approximately 20 miles (Fig. 2). The areal sectional maps of Figure 3 illustrate the distribution of formations comprising Little North Mountain in Frederick County. The sectional maps have been taken directly from the map prepared by Butts and Edmundson[19] and were selected where the stratigraphic discontinu-

[19] Butts and Edmundson, *op. cit.*, Pl. 23.

ities marking the trend of Little North Mountain are well displayed. Their combined length is approximately 16 miles.

Map *A*, Figure 3, illustrates the distribution of formations in the vicinity of Green Springs $2\frac{1}{2}$ miles south of the Virginia–West Virginia boundary. The structure at Green Springs was interpreted by

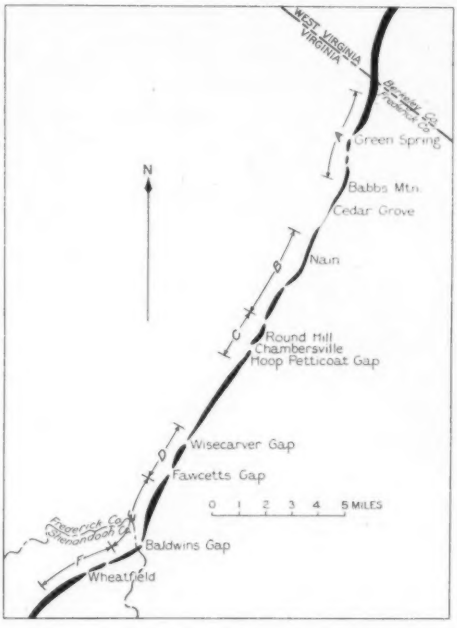


FIG. 2.—Course of Little North Mountain across Frederick County in northern Virginia showing the numerous gaps and location of sectional maps illustrated in Figure 3.

Giles[20] as due to faulting which cut out part of the Tuscarora, all the Clinton and Cayugan, and nearly all the Helderberg. A short distance south of Green Springs the Tuscarora is absent, the Martinsburg lying against the Lower Devonian, with all the Silurian gone. One-half mile farther south the Lower Devonian has disappeared, and the Martinsburg lies against the Onondaga shale. Butts and

[20] Giles, *op. cit.*, Fig. 4, cross section 6.

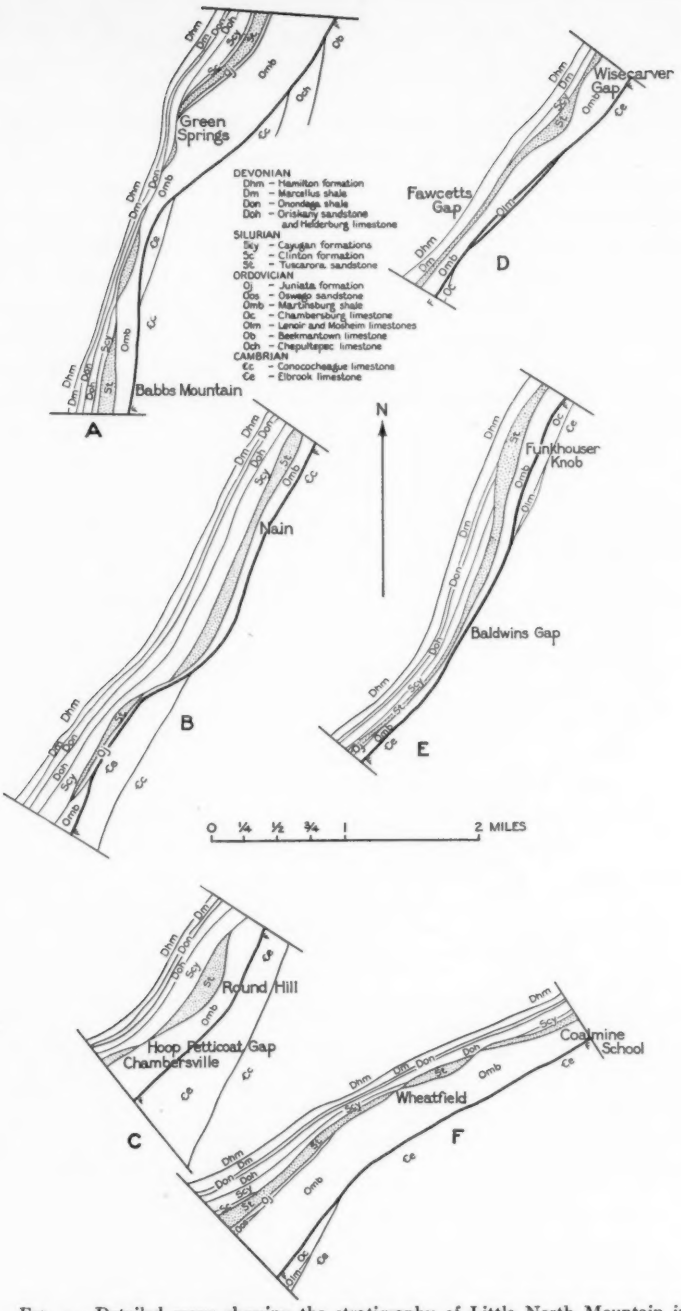


FIG. 3.—Detailed maps showing the stratigraphy of Little North Mountain in northern Virginia. Based on mapping by Butts and Edmundson.

Edmundson describe the structural features in the vicinity of Green Springs as follows:

> The Silurian formations diminish in thickness from the Virginia boundary to a point just north of the gap west of Green Springs. Here the Juniata, Tuscarora, Clinton and Cayugan sandstones and shales show a rather sharp flexure to the southeast and apparently end abruptly against the underlying Martinsburg shale. It is reasonably certain that a minor fault, in conjunction with pronounced thinning, must be postulated to explain the distribution of the formations at this locality. This oblique fault apparently extends to the southwest for about 2 miles and dies out as a strike fault along the northeastern slope of Babbs Mountain. Through the Green Springs water gap the overturned formations in ascending order are Martinsburg, Helderberg-Oriskany, Onondaga Marcellus, and Hamilton.[21]

Apparently, Butts and Edmundson recognize faulting as the fundamental cause of the structure illustrated in Map *A*, Figure 3.

The map of the geology in the vicinity of Nain, 5 miles south of Green Springs, illustrates the rapid thinning and thickening of the Tuscarora, as well as its deletion within short distances (Fig. 3, Map *B*). The width of outcrop of the Cayugan is equally variable. The Clinton is absent. According to Butts and Edmundson, the Clinton is absent "for about 20 miles" from the vicinity of Green Springs to the southern part of Frederick County. About 1 mile south of Nain the Tuscarora disappears, the Martinsburg lying against Cayugan. In describing the structure at this locality Butts and Edmundson state that "it is not impossible that compression at this place or relative weakness, due to thinning of the Tuscarora, may have resulted in minor faulting, but the lack of any noticeable distortion in the associated beds rather favors a sedimentary unconformity."[22]

About 8 miles south of Green Springs at Round Hill a similar structure is mapped by Butts and Edmundson (Fig. 3, Map *C*). North of Round Hill the Tuscarora and Clinton are missing, bringing the Martinsburg against the Cayugan. South of Round Hill at Chambersville the Tuscarora and Clinton are again missing, the Martinsburg lying against the Cayugan. The cross section through Chambersville is illustrated by Giles.[23] Here Butts and Edmundson identify the Clinton as Cayugan and interpret the structure as follows: "The thinning and omission of the Tuscarora sandstone near

[21] Butts and Edmundson, *op. cit.*, p. 175.

[22] *Ibid.* [23] Giles, *op. cit.*, Fig. 5, cross section 9.

and in Hoop Petticoat Gap may be due in part to some local readjustment in the weak zone, but the important structural feature is believed to be directly connected with primary deposition."[24]

Round Hill is described as follows:

> Along the northeast slope of Round Hill the Tuscarora begins as a thin formation, rapidly increases to a maximum thickness of about 250 feet near the summit, and then gradually thins out at Hoop Petticoat Gap, west of Chambersville along U.S. Route 50. To interpret this feature as a depositional lens seems highly speculative, yet an original local basin of deposition with an initial dip of about 5 degrees would probably explain it.[25]

About $4\frac{1}{2}$ miles south of Chambersville is Wisecarver Gap, and $1\frac{1}{2}$ miles farther south Little North Mountain is again interrupted by Fawcetts Gap (Fig. 3, Map *D*). The section through Wisecarver Gap "is noteworthy because of the absence of the Helderberg limestones and Onondaga shale."[26] The section through Fawcetts Gap includes but 5 feet of Tuscarora bounded on the east by the Martinsburg shale and on the west by the Marcellus shale. A cross section through the gap has been illustrated by Giles.[27]

Describing the structure section through Fawcetts Gap, Butts and Edmundson state:

> The absence particularly of the Cayugan, Helderberg-Oriskany, and Onondaga formations make this section unique for the part of Little North Mountain discussed in this paper. The explanation of this phenomenon may be a matter of some conjecture, but the lack of any apparent distortion, such as drag folding and brecciation of the associated beds, and the observed gradual diminution in thickness and final disappearance of the formations north of Fawcetts Gap suggest some depositional and erosional causes rather than faulting. It should be emphasized that *the entire Silurian System is represented at this locality by a total thickness of 5 feet.*[28]

The section has also been photographed by Bevan showing the thin Tuscarora lying against the Marcellus with Clinton, Cayugan, Helderberg, Oriskany, and Onondaga formations absent, although no fault is recognized.[29]

About 1 mile southwest of Fawcetts Gap the Tuscarora sandstone thickens and forms Funkhouser Knob with section "similar [to that]

[24] Butts and Edmundson, *op. cit.*, p. 176. [25] *Ibid.* [26] *Ibid.*

[27] Giles, *op. cit.*, Fig. 5, cross section 11.

[28] Butts and Edmundson, *op. cit.*, p. 177. [29] Edmundson, *op. cit.*, p. 538, Fig. 3, *C*.

of Fawcetts Gap, except for the thickened Tuscarora," according to Butts and Edmundson. Between the gap and the knob the Tuscarora is mapped by them as a thin but continuous formation, "but it is possible instead that it occurs in a series of thin lenses."[30]

On the southwest side of Funkhouser Knob the Cayugan, Helderberg, Oriskany, and Onondaga terminate successively against the Tuscarora of the knob (Fig. 3, Map *E*). This relationship is described by Butts and Edmundson as an overlap.[31] According to this interpretation, four formations ranging from the Middle Silurian into the Middle Devonian, having an aggregate thickness of 1,000 feet, overlap and disappear within a distance of less than 1 mile. If this interpretation is correct, it is a very unusual and remarkable example of overlap. Butts and Edmundson have prepared a cross section through Funkhouser Knob,[32] and Giles one through Baldwins Gap, a mile farther south.[33] In the latter section the Cayugan is represented in contact with the Romney; but, according to Butts and Edmundson, the sequence is Cayugan, Helderberg, and Onondaga (Romney) with no Oriskany.

Two and one-half miles southwest of Baldwins Gap is Wheatfield, lying in another gap of Little North Mountain (Fig. 3, Map *F*). Here the Tuscarora is absent. Three-fourths of a mile northeast of Wheatfield the Tuscarora is again absent, a thin lens of Tuscarora intervening between two gaps. West of Wheatfield the Clinton is absent, and the Cayugan terminates northward against the intervening lens, to be resumed again north of the next gap. In this gap "the Martinsburg shale is adjacent to Helderberg limestone without any visible evidence of brecciation, drag folding, or other structural features which would suggest faulting." In fact, "discontinuous outcrops of several formations are the rule between the gap east of Coalmine School and Wheatfield."[34]

South of Wheatfield, continuing into Shenandoah County, all the formations above the Tuscarora are present, according to Butts and Edmundson, although the "section is not continuously exposed."

[30] Butts and Edmundson, *op. cit.*, p. 177.

[31] *Ibid.*

[32] *Ibid.*, Pl. 23, cross section *GG'*.

[33] Giles, *op. cit.*, Fig. 5, cross section 12.

[34] Butts and Edmundson, *op. cit.*, p. 178.

EVALUATION OF DETAILED STRUCTURAL EVIDENCE

As is well known, the stratigraphic evidence suggesting faulting consists essentially of discontinuity of linear outcrops along the strike of the supposed fault, repetition of the same beds and abrupt termination of formations along the strike, and omission of formations which are part of the normal stratigraphic sequence of the region. These criteria are universally used in the interpretation of Appalachian structure and the recognition of faults. The application of these criteria leads to the conclusion that faulting along the west side of Little North Mountain most satisfactorily explains the distribution of the formations involved in the uplift. It would be difficult to find a locality of similar area where discontinuity of linear outcrops, abrupt termination of formations along the strike, and repeated omission of formations are better displayed than along the western side of Little North Mountain. These structural features are well illustrated in the map prepared by Butts and Edmundson showing the geology of Little North Mountain,[35] which has been used as the basis for the sectional maps of Figure 3.

Although the interpretation by Butts and Edmundson of the areal distribution and thinning of formations composing Little North Mountain is contrary to the generally accepted principles used in interpreting structure, their proposed explanation of the structure suffers further by the adoption of different explanations for similar areal relationships exhibited by the formations. They interpret the structure in the vicinity of Green Springs as due to faulting (Fig. 3, Map *A*). South of Nain the juxtaposition of the Martinsburg and Cayugan may have resulted from "minor faulting,"[36] although a "sedimentary unconformity" is favored (Map *B*). Near Chambersville the "thinning and omission of the Tuscarora sandstone near and in Hoop Petticoat Gap may be due in part to some local readjustment in the weak zone, but the important structural feature is believed to be directly connected with primary deposition" (Map *C*). The interpretation of the Tuscarora at Round Hill as a depositional lens "seems highly speculative" but is nevertheless favored by them (Map *C*). The deletion of all the Silurian but 5 feet of Tuscarora at Fawcetts Gap is regarded by Butts and Edmundson as "unique,"

[35] *Ibid.*, Pl. 23. [36] *Ibid.*, p. 175.

and "the explanation of this phenomenon may be a matter of some conjecture" (Map *D*). Nevertheless, it is suggested to be due to "depositional and erosional causes rather than faulting." The abrupt termination against Funkhouser Knob of the Upper Silurian and Lower Devonian formations with a maximum thickness of 1,000 feet is ascribed to overlap by Butts and Edmundson (Map *E*). "The discontinuous outcrops of several formations" between Wheatfield and Coalmine School and the juxtaposition of Martinsburg shale and Helderberg limestone with all the Silurian formations missing do not "suggest faulting" to Butts and Edmundson, although all the Silurian formations are present 1½ miles south of Wheatfield according to their mapping (Fig. 3, Map *F*).

The evidence presented by Butts and Edmundson to account for the lenticular distributions of formations of Little North Mountain as due to irregularities of deposition rather than to faulting is both inadequate and unconvincing. The similarity of the structure along the western flank of Little North Mountain demonstrates the operation of a single cause in its origin; yet Butts and Edmundson employ different explanations to account for similar structures. Faulting, the most obvious explanation, is avoided. Why faulting, which would seem to be the rational explanation of the phenomena described by Butts and Edmundson, is so rigidly excluded by them is not obvious, and they offer no valid evidence that faulting is not the cause of the irregular distribution of the formations.

The structure of Little North Mountain in northern Virginia may be illustrated by the section through Fawcetts Gap, as interpreted in Figure 4. The trace of the main overthrust lies east of the mountain crest. A parallel overthrust trends northeastward west of the mountain crest. The latter is an auxiliary of the main overthrust. In the vicinity of Fawcetts Gap the main overthrust is a double fault. According to this interpretation of its structure, Little North Mountain may be regarded as an anticline overturned toward the west and broken and thrust over the edge of the syncline. This interpretation agrees with the interpretation of the structure of North Mountain in West Virginia proposed by Stose and Swartz.[37] Edmundson also regards the structure of Little North Mountain as an overturned and

[37] *Op. cit.*, p. 17, Fig. 7.

faulted anticline of which only the northwest limb is now preserved.[38] He fails, however, to recognize the faulting west of the mountain crest. Edmundson also compares the structure of Little North Mountain with that of Great North Mountain, which lies 6 miles farther west. Great North Mountain is interpreted by him as a broad anticline with "marked stratigraphic regularity" in contrast to the "varied discontinuities" of Little North Mountain. He attributes

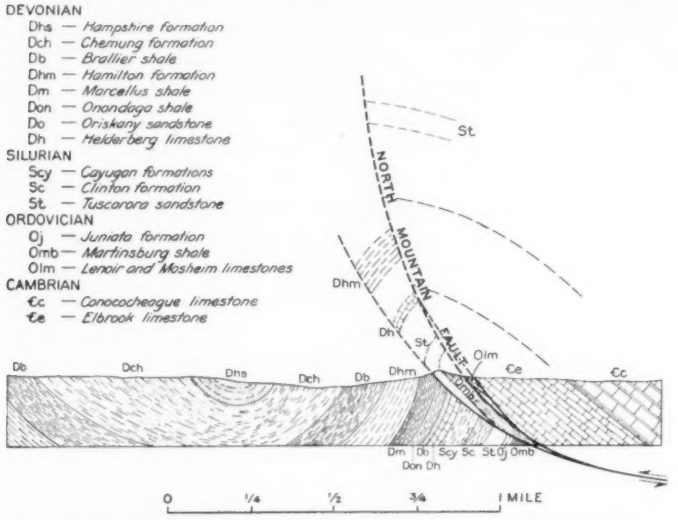


FIG. 4.—Structure of Little North Mountain at Fawcetts Gap. Distribution of formations based on mapping by Butts and Edmundson.

the stratigraphic contrast primarily to differences in sedimentation. Why there should be such a marked difference in sedimentation within adjoining areas is not apparent. Rather, the difference in structure and stratigraphic regularity appears to imply progressive absorption of stress westward. The diminution westward of the severe compression which resulted in faulting and thinning, producing the varied discontinuities exhibited by the formations in Little North Mountain, is reflected in open folding with absence of faulting resulting in stratigraphic continuity farther west in Great North

[38] Edmundson, *op. cit.*, Fig. 5.

Mountain. Progressive diminution westward of the intense effects of compression is observable throughout the Appalachians and is well illustrated in innumerable published transverse structure sections of the Appalachian Province.

Edmundson has used the term "Little North Mountain fault" for the main fault lying east of Little North Mountain.[39] This term is

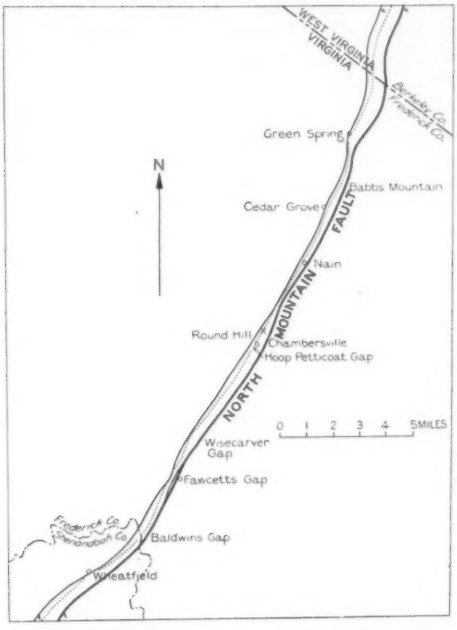


FIG. 5.—Trace of North Mountain fault and its western auxiliary in northern Virginia. Dotted line represents the crest of Little North Mountain.

inappropriate since the term "North Mountain fault" was proposed thirty years ago by Stose and Swartz for the continuation of the same fault east of North Mountain in West Virginia.[40] For this reason the term used by Edmundson is here discarded, and the term "North Mountain fault" will be used for its southward continuation east of Little North Mountain in Virginia (Fig. 5).

[39] *Ibid.*, p. 544.

[40] Stose and Swartz, *op. cit.*, p. 17.

CONTINUATION OF NORTH MOUNTAIN FAULT

North of Virginia the North Mountain fault is mapped by Grimsley[41] and by Stose and Swartz.[42] In Maryland, North Mountain fault is mapped by Bassler[43] and by Swartz.[44] Both Bassler and

FIG. 6.—Trace of North Mountain fault and its western auxiliary in Virginia and adjacent states.

Swartz map the northward termination of the North Mountain fault at the southern end of Powell Mountain in northern Maryland about 3 miles south of the Pennsylvania state line (Fig. 6). The state

[41] *Op. cit.*, plate facing p. 120.

[42] *Op. cit.*, Hancock quadrangle.

[43] *Op. cit.*, Pl. I.

[44] *Op. cit.*, Pl. I.

geologic map of Pennsylvania (1931) shows a fault in line with the North Mountain fault at the southern edge of the state. The continuation of this fault is mapped on the Mercersburg quadrangle, terminating northward about 5 miles northeast of Mercersburg.[45] If this fault is the continuation of North Mountain fault, the total length of the latter north of Virginia is about 40 miles. On the Virginia Geologic Map (1928) the North Mountain fault continues from the West Virginia state line southward into southern Augusta County, a distance of 110 miles. Throughout this distance the fault is mapped adjacent to the course of Little North Mountain. Throughout much of the distance from Maryland into Rockingham County, Virginia, the western auxiliary of the North Mountain fault is recognized and mapped on the west side of Little North Mountain (Fig. 6). The numerous gaps in Little North Mountain throughout this distance strongly suggest that the Tuscarora sandstone which forms the mountain range has been repeatedly thinned or deleted by this subsidiary fault, permitting the formation of the gaps in the less resistant formations flanking the sandstone.

## CONCLUSIONS

On the basis of both stratigraphic and structural evidence the structure of Little North Mountain appears to be most satisfactorily interpreted as a remnant of an anticline bounded by an overthrust on the east with a persistent auxiliary fault on the west side of the mountain. The structure developed as an anticline which was overturned to the northwest and broken, the eastern limb being thrust over the edge of the syncline to the west. The failure to recognize the significance of subsidiary faulting in producing the stratigraphic irregularities characteristic of this part of Little North Mountain has led Butts and Edmundson to erect a highly speculative concept to explain the irregularities as due to the vagaries of nearshore sedimentation. The stratigraphic and structural evidence affords no basis for such an assumption, which implies that the present site of Little North Mountain on the west side of the Shenandoah Valley was in proximity to the eastern shoreline of the Appalachian geo-

[45] Stose, "Chambersburg-Mercersburg Folio No. 170," *Geologic Atlas of the United States* (1909).

syncline "from Upper Ordovician to Lower Devonian inclusive." Such an assumption is contrary to the generally accepted conclusions reached after a century of study of the Appalachian geosyncline. Since the formations involved are typical offshore deposits and are widely distributed in eastern United States, the proposed explanation by Butts and Edmundson has no valid stratigraphic basis. The irregularities exhibited by the formations of Little North Mountain can be satisfactorily explained only on the basis of faulting. The stratigraphic evidence suggesting faulting, well known and universally used in interpreting structure, is as well displayed along Little North Mountain in northern Virginia as anywhere in the Appalachians. Aside from minor changes in stratigraphic details, the recent contributions to the geology of Little North Mountain of northern Virginia present little that was not known a quarter of a century ago.

# CONTRIBUTIONS OF BOTANICAL SCIENCE TO THE KNOWLEDGE OF POSTGLACIAL CLIMATES[1]

WILLIAM S. COOPER
University of Minnesota

ABSTRACT

Botanical science contributes to the knowledge of postglacial climates through inference from fossils and from the distribution of existing vegetation. In the first field the materials include complete plant communities of the past preserved intact and individual plants and plant parts. The bogs of the glaciated region furnish as evidence successive layers of peat of differing character and pollen grains of plants which grew at successive periods. Analysis of the pollen content of the stratified bog deposits is yielding a wealth of evidence concerning post-Pleistocene forest history and therefore as to the concomitant climatic sequence. In inference from present distribution of vegetation, relic colonies of plants are considered as indicators of earlier dominance of types different from those of today and therefore of climatic change. There is almost universal agreement among students of these phenomena that the evidence from fossils and from present distribution indicates a postglacial climatic sequence as follows: from glacial through boreal to a warm and probably dry middle period, followed by a return to the cooler and probably moister conditions of the present. Several nonbotanical lines of investigation provide evidence supporting or consistent with this sequence.

## INTRODUCTION

Botanical science contributes to the knowledge of postglacial climates in two general ways: one—inference from fossils—is geologic in method; the other—inference from the distribution of existing vegetation—is a purely biologic line of attack.

## INFERENCE FROM FOSSILS

In utilizing the first approach, fossils must be taken in the broadest sense, including all sorts of plant remains and without regard to state of preservation. The basic assumption, as in all use of fossil evidence, is that organisms are reliable indicators of the nature of their environment, including climate.

The student of paleoecology is happiest when he discovers the remains of a complete plant community of the past preserved intact. It has been my good fortune to study such a community at Glacier

[1] Address delivered at the Fiftieth Anniversary Celebration, University of Chicago, September, 1941.

Bay, Alaska, a brief description of which will provide an excellent point of departure for the present discussion.[2]

Following an ice maximum of about two centuries ago, recession has laid bare the shores of the bay, bringing to light the remains of a forest that had been buried by hundreds of feet of gravel and thousands of feet of advancing ice. The Muir Glacier in its continued recession is still uncovering remains of mature forest 45 miles within the limit of the recent maximum, and in 1941 a tree trunk was found close to the ice margin of that year which showed at least 480 growth rings. Drawing upon this and other lines of evidence, a minimum elapsed time of two thousand years since the establishment of the forest seems fairly certain. There are no known facts that will hinder us from pushing it farther back into the past.

The character of this forest does not indicate a climate profoundly different from that of the coastal strip today. Its former extent, however, does indicate a significant climatic change, since it demonstrates conclusively that two thousand or more years ago the ice fields of the region were considerably less extensive than now.

In many other localities in southeastern Alaska there is botanical evidence of a major maximum in very recent time. In a rather important minority of cases the ice is now actually at flood, invading forest and other vegetation which required several and perhaps many centuries to develop. A preceding period of ice contraction is a necessary corollary.

In a recent paper[3] dealing with Alaskan studies these phenomena are discussed, and the hypothesis is offered that the "present," liberally construed, in coastal Alaska is a time of ice expansion on a scale not equaled during many centuries of the past. It is quite reasonable to suppose that the high ice mark of two hundred years ago at one point and of today at another represent a single major maximum, reaching its crest in different places at slightly different times. Associated with this hypothesis is the suggestion that the preceding

[2] W. S. Cooper, "The Problem of Glacier Bay, Alaska: A Study of Glacier Variations," *Geog. Rev.*, Vol. XXVII (1937), pp. 37–62. Reference is made to other publications which give the botanical evidence in detail.

[3] Cooper, "The Vegetation of the Prince William Sound Region, Alaska; with a Brief Excursion into Postglacial Climatic History," *Ecol. Mono.*, Vol. XII (1942), pp. 1–22.

period of contraction, during which the now buried forests grew, was of a magnitude so great as to make it the major glacial event of mid-post-Pleistocene time, and that the cause was the oncoming of a period warmer and perhaps drier (in coastal Alaska, strictly speaking, less wet) than the present.

Preservation of a complete community is comparatively rare; for the most part reliance must be placed upon more fragmentary evidence. Plant parts washed into ponds and buried there by sedimentation, organic soil layers overwhelmed by eolian deposits, ancient soil profiles—in northern regions principally podzols—all indicate something as to climatic conditions. The difficulty usually lies in dating them even approximately.

By far the most important body of evidence is contained in the bogs of the glaciated region, where low temperature and lack of aeration have made possible the preservation of plant parts and where continuous organic sedimentation has laid down deposits in chronological order. There are materials for study here in embarrassing profusion; their use is limited only by the number of investigators.

Bog study has been carried forward along two principal lines—peat stratigraphy and pollen analysis. The first is the more obvious and therefore was developed earlier. The character of the peat itself at successive horizons indicates something of changing climatic conditions. Dark, partly macerated material, derived from aquatic and amphibious plants, denotes a high ground-water level, and therefore a moist climate; fibrous or woody peat indicates a low water level and dry climate. Recognizable plant parts and stumps in place at certain levels are valuable aids in deciphering the history.

The method has been much elaborated in northern Europe, and a climatic sequence based upon peat layers and plant fossils has been worked out which is commonly known as the Blytt-Sernander hypothesis. After the arctic and subarctic periods which followed immediately the disappearance of the ice, came in order the boreal (warm-dry), Atlantic (warm-humid), subboreal (warm-dry), and sub-Atlantic (cool-humid). Attempts have been made to link these divisions with stages of the Baltic and with archeological periods,

and to date them by means of DeGeer's varve chronology.[4] On this continent the method has been developed principally by A. P. Dachnowski-Stokes,[5] who believes that there is general agreement with the Blytt-Sernander scheme.

Of late there has been a tendency, both in Europe and North America, to abandon the Blytt-Sernander hypothesis as being too rigid to permit general application and to accept as a provisional framework the simpler scheme proposed by L. von Post and based mainly upon pollen analysis, which postulates three periods. In the words of von Post himself,[6] these are as follows:

1. The stage of the approach of the warm period, characterized by the appearance and the first increase of relatively heat-loving trees of different kinds.
2. The stage of the culmination of these forest-elements.
3. The stage of the decrease of the characteristic trees of the warm period and the appearance or the return of the predominant forest-constituents of the present day.

It is an indication that we are on the right track that the two schemes, based on different sorts of evidence, are not in conflict, for the Blytt-Sernander scheme, like von Post's, postulates a lengthy period of warmth in mid-post-Pleistocene time; it differs in recognizing within this two dry subperiods separated by a moist one.

The plant parts preserved in bogs that have yielded most satisfactory evidence as to past vegetation and climate are pollen grains, and their study during the last quarter-century has developed into a highly specialized field with an elaborate technique. Three excellent critical surveys have appeared in recent years, by P. B. Sears,[7] L. C. Eiseley,[8] and S. A. Cain.[9]

[4] H. Godwin, "Pollen Analysis: An Outline of the Problems and Potentialities of the Method," *New Phytologist*, Vol. XXXIII (1934), pp. 278–305, 325–58; Erik Fromm, "Geochronologisch datierte Pollendiagramme und Diatoméenanalysen aus Ångermanland," *Geol. fören. i Stockholm förhandl.*, Vol. LX (1938), pp. 365–81.

[5] "Records of Climatic Cycles in Peat Deposits," *Carnegie Inst. Wash., Reports of the Conferences on Cycles* (1929), pp. 55–64.

[6] "Problems and Working-lines in the Post-Arctic History of Europe," *Rept. Proc. 5th Internat. Bot. Cong., Cambridge, 1930* (1931), pp. 48–54.

[7] "Glacial and Postglacial Vegetation," *Bot. Rev.*, Vol. I (1935), pp. 37–51.

[8] "Pollen Analysis and Its Bearing upon American Prehistory: A Critique," *Amer. Antiquity*, Vol. V (1939), pp. 115–39.

[9] "Pollen Analysis as a Paleo-ecological Research Method," *Bot. Rev.*, Vol. V (1939), pp. 627–54.

The basic assumptions upon which the method rests are thus stated by Cain (I have condensed his full statement):

1. The structural characteristics of pollen grains are constant for a species.
2. Most dominant trees of the temperate zone have wind-borne pollen.
3. Many of the grains of the pollen rains which fall onto a bog surface are preserved under the antiseptic, low-oxidation conditions.
4. Year after year, as the peat accumulates, stratified pollen deposits occur.
5. Proper methods allow the detection, identification, and counting of the fossil pollen grains.
6. Consistent general trends in the pollen spectra from the samples of a boring, based on percentage composition, are a fact in most records. As a result, stratigraphic-time-vegetation-climate correlations can be made.

The method is thus after a fashion a quantitative one. It was devised in Sweden, and an enormous amount of work in the field has been done in northern Europe. G. Erdtman[10] lists more than fourteen hundred published works through the year 1934. Investigations in North America began about fifteen years ago, and up to the present at least seventy papers have appeared.

Space does not permit discussion of technique or of the many difficulties and serious sources of error which are inevitable. These have been fully considered and allowance made so far as possible.[11] I will confine myself to a brief statement of results obtained.

The most important result of work in Europe has been the development of the climatic sequence of von Post. It is admittedly a generalized outline of major trends into which the minor events must be fitted; and such refinement is the order of the day.

In America, because of the enormous amount of territory to be covered and the comparatively small number of workers, conclusions must be far more tentative than in Europe. Most of the studies have been made in the glaciated portion of the northeast, and the present discussion will be confined to that region.[12]

[10] "Literature on Pollen-Statistics and Related Topics Published 1934," *Geol. fören i Stockholm förhandl.*, Vol. LVII (1935), pp. 261–74. Earlier papers listed.

[11] Cain, *op. cit.;* Eiseley, *op. cit.;* Godwin, *op. cit.*

[12] A number of studies have been made in the Pacific Northwest, most of them by H. P. Hansen. His earlier works are cited in a recent paper: "A Pollen Study of Post-Pleistocene Lake Sediments in the Upper Sonoran Life Zone of Washington," *Amer. Jour. Sci.*, Vol. CCXXXIX (1941), pp. 503–22. A few investigations have been made in extraglacial regions, e.g., I. F. Lewis and E. C. Cocke, "Pollen Analysis of Dismal Swamp Peat," *Jour. Elisha Mitchell Sci. Soc.*, Vol. XLV (1929), pp. 37–58; Cocke and

Four characteristic profiles will be presented, distributed from northern Illinois to northern Minnesota. The first, from Hastings, Illinois,[13] will serve to illustrate the accepted method of portraying results (Fig. 1, *A*). The ordinates represent depth of peat and the abscissas percentages of total pollen grains counted for each genus at each depth. Each genus has a distinctive symbol. The columns at the right show character of peat and total number of grains counted.

The Hastings bog shows, first of all, a feature that is outstanding wherever studies have been made in northeastern America—dominance of spruce (Picea) and fir (Abies) in the oldest sediments. This is followed by complete, rather sudden, and final disappearance of these genera—a phenomenon practically universal in bogs of the *southern* part of the glaciated regions. With decline of spruce and fir comes rapid increase of oak (Quercus), which maintains its dominance to the end. Pine (Pinus) is present in small quantity throughout. Other deciduous genera represented in minor amounts, not recorded on the diagram, are alder, birch, hickory, walnut, poplar, willow, basswood, and elm. This is the characteristic southern profile, showing initial dominance of the spruce-fir type and its early and complete disappearance.

Considered alone, this type of profile seems to indicate merely a simple progressive climatic change, from glacial through a comparatively short period of boreal conditions to a long period much like the present. It is, however, only a part of the picture. Farther north, near Minneapolis,[14] there is the same early disappearance of spruce and fir as before and their replacement by pine and oak; pine, however, is more important than oak (Fig. 1, *B*). The most significant difference is the reappearance of spruce at the top of the column. Near Brainerd, Minnesota, still farther north,[15] spruce is present

Lewis, "A Further Study of Dismal Swamp Peat," *Amer. Jour. Bot.*, Vol. XXI (1934), pp. 374–95; P. B. Sears and G. C. Couch, "Microfossils in an Arkansas Peat and Their Significance," *Ohio Jour. Sci.*, Vol. XXXII (1932), pp. 63–68.

[13] John Voss, "Postglacial Migration of Forests in Illinois, Wisconsin, and Minnesota," *Bot. Gaz.*, Vol. XCVI (1934), pp. 3–43.

[14] R. C. Artist, "Pollen Spectrum Studies on the Anoka Sand Plain in Minnesota," *Ecol. Mono.*, Vol. IX (1939), pp. 493–535.

[15] Voss, *op. cit.*

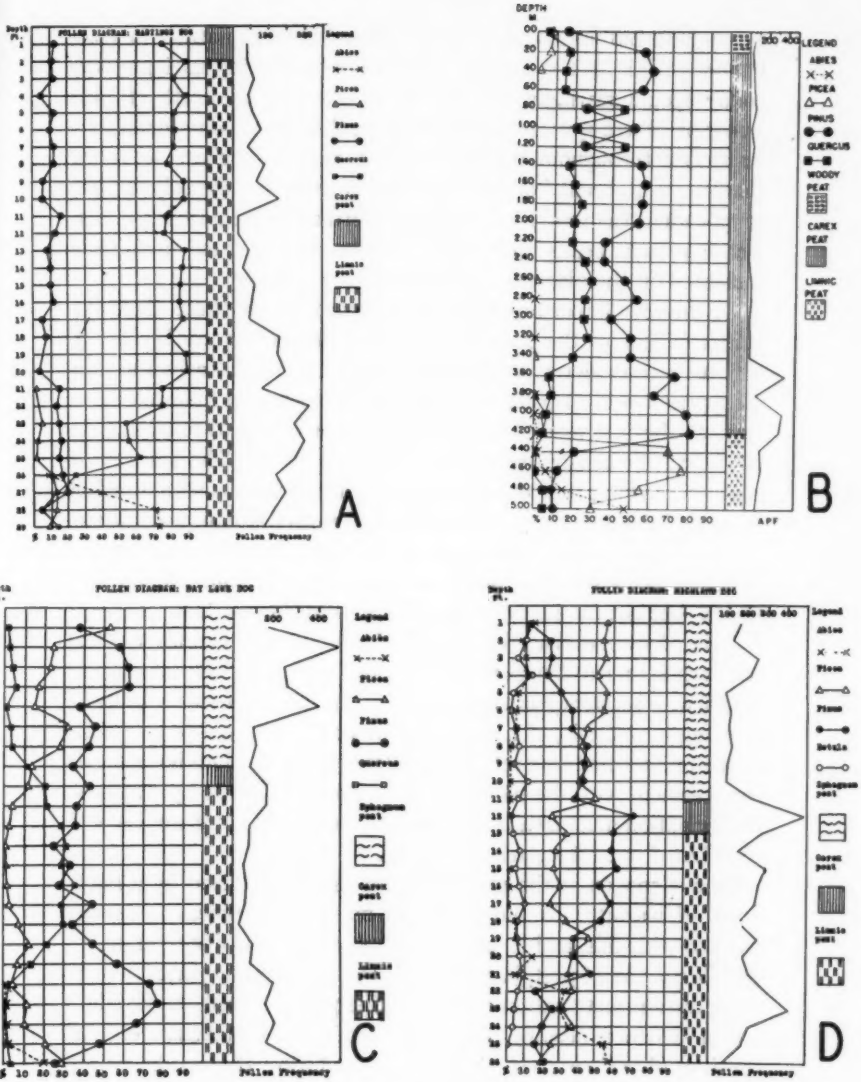


FIG. 1.—Four pollen profiles: *A*, Hastings, northeastern Illinois (Voss); *B*, near Minneapolis, Minn. (Artist); *C*, Near Brainerd, Minn. (Voss); *D*, Highland, Minn. (Voss). For discussion see text.

throughout but is scanty in the middle and shows a notable increase at the top (Fig. 1, *C*). Here and around the preceding station spruce today occurs sparingly. At Highland, Minnesota,[16] north of Lake Superior, where spruce is a dominant in the present-day forest, it is important throughout the column (Fig. 1, *D*). Fir shows an initial maximum, is absent from a portion of the middle of the column, and reappears at the top. Pine is most important in the middle portion. Oak is present nearly throughout, but in quantities too small to be indicated on the diagram.

Of the four important tree genera appearing on these diagrams, spruce is best for the purpose of illustration and is probably as significant as any as an indicator of climatic change. Early and final disappearance of its pollen southward, disappearance followed by return at the intermediate stations, and abundance throughout the profile at the north suggest the following story. The spruces receded northward before the advance of the deciduous trees to a line beyond their present southern limit, and rather late in post-Pleistocene time they readvanced southward far enough so that the bogs of the intermediate region again received an appreciable amount of pollen, but not far enough to deposit any in the southern bogs.

It is, of course, true that not all the profiles studied are as clear cut in their indications as those here presented, but there seems to be sufficient consistency among them to warrant the assumption, as a working hypothesis, of a maximum of warmth in mid-post-Pleistocene time followed by a return to cooler conditions. This is obviously in agreement with the sequence worked out in Europe by von Post. Confirmation must await the completion of many more studies, well distributed over the glaciated region.

I have spoken of the middle period as characterized by a maximum of warmth. In the literature maximum dryness is usually coupled with this, and it has thus become customary to refer to the middle portion of postglacial time as the xerothermic period. There is no certain justification for this in the pollen record. Some slight pollen evidence, needing confirmation, of a prairie invasion of Wisconsin and regions west and southwest during the middle period may be an indication of dry climate at that time. In making infer-

[16] *Ibid.*

ences as to past climates we are depending entirely upon what is known concerning the reaction of key plant species to climatic factors. This knowledge is so fragmentary and inadequate that great caution in drawing conclusions is essential.

The above interpretation is frankly the writer's own. It is, however, in essential agreement with conclusions already set forth by several authors. Sears's statement of the case is as follows:

> The most evident generalization to be drawn from the diagrams is that distinctive regional pollen profiles are a reality.
>
> A second major generalization appears to be this: The climatic shift accompanying glacial retreat was of a much greater order of magnitude than any fluctuations which have occurred since. . . . . The third major generalization, namely, that the evidence indicates a period of maximum warmth and probably dryness now past.[17]

G. D. Fuller thus presents his view:

> A threefold division of postglacial time on a climatic basis as postulated by von Post seems fairly well marked in the mid-lake records, viz., (1) a well marked period of increasing warmth; (2) a long period of maximum warmth; and (3) a poorly emphasized period of decreasing warmth.[18]

E. S. Deevey, Jr.,[19] believes that "the existence of a postglacial climatic optimum is exceedingly well-attested by many diverse indications." By means of a diagram[20] he shows how a late return to moderately cool-moist conditions might not be obvious too far north or too far south—as I have endeavored to do in a different way earlier in this paper.

Certain other authors hold views divergent in some respects from those here advocated. Voss,[21] from a study covering bogs in Illinois,

[17] "Types of North American Pollen Profiles," *Ecology*, Vol. XVI (1935), pp. 488–99. Since this paper went to press, Sears has published two papers which should be noted here: "Forest Sequences in the North Central States," *Bot. Gaz.*, Vol. CII (1942), pp. 751–61, and "Postglacial Migration of Five Forest Genera," *Amer. Jour. Bot.*, Vol. XXIX (1942), pp. 684–91. In these he presents evidence, based mainly upon the postglacial behavior of certain deciduous tree genera, supporting the hypothesis of threefold division of middle post-Pleistocene time into warm-dry, warm-moist, and warm-dry stages.

[18] "Postglacial Vegetation of the Lake Michigan Region," *Ecology*, Vol. XVI (1935), pp. 473–87.

[19] "Studies on Connecticut Lake Sediments," *Amer. Jour. Sci.*, Vol. CCXXXVII (1939), pp. 691–724.

[20] *Ibid.*, Fig. 11, p. 720.

[21] *Op. cit.*, p. 40.

Wisconsin, and Minnesota, concludes that "climatic conditions remained very uniform throughout the period represented by the upper two-thirds of the pollen diagrams." It is a pointed commentary upon the risks involved in interpretation based upon scanty data that I have cited, earlier in this paper, three of Voss's profiles in support of my interpretation, which differs radically from his. Voss dismisses the increase of spruce at the top of the column in central Wisconsin and central Minnesota as owing probably to invasion of mature bogs by black spruce in the course of normal plant succession.

L. R. Wilson drew the following conclusions from his investigations in northwestern Wisconsin:

> 1. The use of pollen statistics is not a reliable indicator of climatic changes in northwestern Wisconsin.
>
> 2. Changes in pollen percentage in the spectra may be explained also upon the basis of some ecological factor other than climate. . . . .
>
> . . . . . .
>
> 5. These conclusions are not suggested for wide application, but may indicate that a climatic interpretation of microfossil spectra be less certain than formerly considered.[22]

In a recent letter, however, Dr. Wilson states his belief that "it is difficult to explain the history of postglacial vegetation without an event such as a xerothermic period. The story that I worked out in Douglas County, Wisconsin, fits the picture very well."

The question of what sort of climatic conditions prevailed at the ice front during its recession presents an interesting problem. The testimony of pollen profiles is entirely negative in character. The earliest vegetation type there represented is conifer forest, but the possibility of something hardier preceding it is by no means ruled out.

In northern Europe a wide belt of tundra bordered the ice margin and followed it in its recession. This may be taken as indicating conditions too severe for the establishment of forest, but the inference is not an absolutely certain one. In America there are but

[22] "The Use of Microfossils as a Means of Studying Paleoclimatic Conditions in Northwestern Wisconsin," *Bull. Amer. Met. Soc.*, Vol. XIX (1938), pp. 186–87. See also "The Postglacial History of Vegetation in Northwestern Wisconsin," *Rhodora*, Vol. XL (1938), pp. 137–75.

scanty data bearing on the problem. Two collections from late Pleistocene deposits in New England[23] have revealed the presence of certain true tundra species such as Dryas, dwarf willow, and Lapland rose bay. They are, however, mingled with nontundra species. The evidence, so far as it goes, suggests that whatever tundra vegetation was present was fragmentary and transitory, constituting the pioneer stage in the normal succession leading to climax conifer forest. There is evidence from Minneapolis, Minnesota, that conifer forest was well established there while the ice edge was certainly not more than 150 miles distant and probably very much closer.[24] It would seem, therefore, that climate along the periphery of the ice sheet during recession was probably not prohibitive to conifer forest. It certainly is not prohibitive in similar situations in Alaska today, where alder thicket and spruce forests grow on ablation moraine resting upon stagnant ice. One must be very cautious, however, in drawing parallels between conditions in Alaska of today and those associated with continental ice sheets, especially in the interior of the continent.

### INFERENCE FROM CONTEMPORARY PLANT DISTRIBUTION

The foregoing contributions of botanical science are essentially geologic in method; they utilize the evidence provided by fossils of various sorts. There is another approach that is quite different. It lies in the field of the plant geographer and makes use of inferences drawn from the present distribution of vegetation. To be more specific, it depends upon interpretation of relic species and colonies.

Isolated plants or groups of plants existing in the midst of an alien population far from their accustomed companions indicate a history of change. They may be either advance guards of an oncoming invasion or relics of past dominance. If they are well developed assemblages of numerous species commonly associated—that is, true

[23] B. K. Emerson, "Geology of Old Hampshire County, Massachusetts," *U.S. Geol. Surv. Mono. XXIX* (1898), pp. 718–20; Arthur Hollick, "Plant Remains from a Pleistocene Lake Deposit in the Upper Connecticut Valley," *Brittonia*, Vol. I (1931), pp. 35–55.

[24] W. S. Cooper and Helen Foot, "Reconstruction of a Late-Pleistocene Biotic Community in Minneapolis, Minn.," *Ecology*, Vol. XIII (1932), pp. 63–72. The trees present were white and black spruce, fir, white pine, tamarack, and paper birch.

plant communities—they are almost certainly remnants, older than the prevailing vegetation that surrounds them. Single species not possessing means of rapid migration are also probably relics, while species of easy mobility may well be recent invaders.

One sort of relic colony has long been recognized—the outlying stands of conifers, with characteristic undergrowth, that occur far south of the southern border of conifer dominance, surrounded by forests of oak, maple, beech, and other deciduous species. Familiar examples are the "tamarack swamps" that are found as far south as northern Illinois and Ohio, and the forests of jack and white pine on the Indiana dunes. It is quite evident that these are relics from the time of conifer dominance which followed close upon the disappearance of the ice and which is recorded universally at the base of the pollen profile.

If there has been a recent southward advance of the conifers at the expense of the deciduous forest, it is to be expected that relic colonies and individuals of the latter may be found surrounded by the invading conifers. Studies by H. M. Raup[25] in southern New England and in New York indicate that such is the case. From the evidence he has obtained Raup infers

> that a warmer and drier climate has occurred in New England within the past 3,000 years. The trend since the peak of the warm dry era has been in general toward the cooler and more moist, but probably with minor variations in the opposite direction. There is evidence, further, that the warm dry climate was so recent that the effects of it are still with us in the form of disrupted ranges for southern animals, plants, and forest types.[26]

Further critical work on such presumptive relics is now in progress in New England and in Minnesota, Wisconsin, Michigan, and southern Ontario.

Isolated areas of grassland vegetation existing within the deciduous forest have with reason been taken to indicate an earlier eastward and northeastward extension of the grassland. H. A. Gleason in a pioneer paper[27] gave expression to this view and pointed to a

[25] "Recent Changes in Climate and Vegetation in Southern New England and Adjacent New York," *Jour. Arnold Arboretum*, Vol. XVIII (1937), pp. 79–117. See also "Botanical Studies in the Black Rock Forest," *black Rock Forest Bull. 7* (1938).

[26] "Recent Changes . . . . ," *op. cit.*, p. 111.

[27] "The Vegetational History of the Middle West," *Annals Assoc. Amer. Geog.*, Vol. XII (1922), pp. 39–85.

xerothermic period as the only adequate explanation. E. N. Transeau, in discussing the origin and history of the "Prairie Peninsula," an eastward protrusion of the grassland across Illinois and Indiana, states that

> a late postglacial prehistoric dry period with more wide spread drought conditions and more prolonged droughts than at present is definitely indicated by certain bog pollen studies, by soil profiles, by the succession in bog profiles, by the absence, or rare occurrence, of many tree, shrub and herbaceous species from the region of the Peninsula, and by the present distribution of prairie colonies and prairie species.[28]

Several plant geographers have found the assumption of a maximum of warmth during a portion of post-Pleistocene time helpful in their attempts to solve certain knotty problems of arctic plant distribution.[29]

Returning to Alaska for a moment: An isolated colony of plants has been reported by Mr. Bradford Washburn from high on the slopes of Mount Bertha, a 10,000-foot peak near Glacier Bay surrounded by many miles of glaciers and snowfields.[30] It is a mixed assemblage of arctic-alpine and low-altitude species which grow in mass great enough to form a turf 2 or 3 inches thick. Recent migration to this spot severely stretches the imagination. A much more easily tenable hypothesis is that the colony has held on from a time of glacier contraction, when migration routes were easy. It thus appears that in the region of Glacier Bay evidence from fossils and from present plant distribution is mutually corroborative in pointing toward a past period of glacier contraction and therefore of milder climate.

It would be strange were there no apparent obstacles to acceptance of the unified climatic history here outlined as applicable to all of North America and Europe. There are, indeed, certain considerations that seem to present difficulties. R. F. Griggs[31] points out evi-

[28] "The Prairie Peninsula," *Ecology*, Vol. XVI (1935), pp. 423–37.

[29] M. P. Porsild, "The Flora of Greenland: Its Affinities and Probable Age and Origin," *Torreya*, Vol. XXII (1922), pp. 53–54; E. C. Abbe, "Phytogeographical Observations in Northernmost Labrador," *Amer. Geog. Soc., Spec. Pub. 22* (1938), pp. 217–34.

[30] Cooper, "An Isolated Colony of Plants on a Glacier-clad Mountain," *Bull. Torrey Bot. Club*, Vol. LXIX (1942), pp. 429–33.

[31] "Timberlines as Indicators of Climatic Trends," *Science*, Vol. LXXXV (1937), pp. 251–55.

dence that seems to indicate differing climatic trends in various parts of North America: rapid advance of forest over tundra in southwestern Alaska (apparently for the first time since the Pleistocene ice maximum), stability of timberlines in the Rocky Mountains, and evidence of increasing cold in northeastern Canada.

> In common with most others, I used to suppose that the great climatic changes indicated in geologic times were worldwide in scope. Conditions here in North America make it clear that shifts in climate of sufficient magnitude to become of geological significance are not necessarily even continental in extent, but may occur in much smaller areas.[32]

Over against these considerations must be placed the botanical evidence summarized in the present paper, which seems to show continental, and even more than continental, uniformity in trend. The evidence from buried forests and other plant phenomena in Alaska, the pollen record in northeastern America and in Europe, and numerous pertinent facts of plant geography—all these apparently agree in indicating the same generalized postglacial climatic sequence: from glacial through boreal to a warm and probably dry middle period, which was followed by a return to the cooler and probably moister conditions of the present.

Furthermore, several nonbotanical lines of investigation in North America provide evidence supporting or consistent with this sequence. There is space only to enumerate them:[33] glacial history in Alaska from strictly geologic evidence, history of saline lakes in the Great Basin, disappearance and reappearance of small glaciers in the Sierra and Rockies, formation of continental sand dunes in the upper Mississippi Valley, and the trend of the geothermal gradient. The weight of this mass of evidence lies not so much in the value of the individual contributions as in their mutual support. No one is decisive; combined, their testimony is impressive.

[32] *Ibid.*, p. 254.

[33] These lines of evidence are discussed in a paper by the present writer, "The Vegetation of the Prince William Sound Region, Alaska; with a Brief Excursion into Post-Pleistocene Climatic History," *Ecol. Mono.*, Vol. XII (1942), pp. 1–22. See also E. Antevs, "Postpluvial Climatic Variations in the Southwest," *Bull. Amer. Met. Soc.*, Vol. XIX (1938), pp. 190–93; F. E. Matthes, "Report of Committee on Glaciers, April, 1939," *Trans. Amer. Geophys. Union, 1939* (1939), pp. 518–23, and "Committee on Glaciers, 1939–40," *ibid., 1940* (1940), pp. 396–406.

# DISCUSSION: WIND WORK ACCOMPANYING AND FOLLOWING GLACIATION

LINCOLN R. THIESMEYER
Illinois Institute of Technology

RALPH E. DIGMAN
Yale University

Dr. Frank Leverett has generously suggested that his recent brief article in this *Journal*[1] was prompted by our description of ventifacts embedded in till of a pre-Wisconsin terminal moraine in Wisconsin.[2] A companion article by Professor W. H. Hobbs[3] appears alongside of that by Leverett. This additional emphasis on the important role played by wind in developing many features hitherto given relatively little attention in glaciated tracts of the Middle West is most welcome. Both articles carry statements and implications that urge us, however, to further comment.

Leverett[4] calls our attention to his earlier interpretation of the age of the Arnott moraine as Illinoian. This age appears also to have been accepted by F. T. Thwaites.[5] We would emphasize that assignment of the moraine to the Kansan was clearly stated to be tentative and only partially justified by evidences we examined.[6] Furthermore, since several writers seem to agree that the till is pre-Wisconsin, our major conclusions concerning the relation of ventifact formation to *a* glacial episode, the emplacement of such wind-modified stones *in* drift deposits, and the probability of finding them at numerous *other* localities hold good, whether the drift be Kansan or Illinoian in age.

[1] "Wind Work Accompanying or Following the Iowan Glaciation," *Jour. Geol.*, Vol. L (1942), pp. 548–55.

[2] "Wind-cut Stones in Kansan Drift of Wisconsin," *Jour. Geol.*, Vol. L (1942), pp. 174–88.

[3] "Wind—the Dominant Transportation Agent within Extramarginal Zones to Continental Glaciers," *Jour. Geol.*, Vol. L (1942), pp. 556–59.

[4] *Op. cit.*, p. 549. [5] Personal communication.

[6] Thiesmeyer and Digman, *op. cit.*, pp. 176 and 187.

Leverett hazards the opinion that the decided faceting of a quartzite boulder illustrated in his paper "may require a more protracted period of wind action than that covered by anticyclonic winds."[7] This speculation must be considered in the light of a woeful lack of quantitative data on many variable factors other than time that are involved in the shaping of a boulder by sandblast action. Size, shape, and lithology of the stone undergoing attack; size, nature, and quantity of the abrasive; speed and constancy in direction of the wind; surface area of the stone exposed at any one time; stability of the stone in position relative to the windstream—all these items should be taken into account before an implied conclusion concerning probable length of exposure is advanced. Since no such measurement of these conditions during the Pleistocene is possible, we have recourse to but two lines of investigation: (1) analogy with present conditions as observed in the field or determined experimentally in the laboratory; and (2) field evidence that a striking amount of wind-sculpturing has been accomplished on quartzite boulders during the interval when anticyclonic winds were active, an interval which Leverett implies was relatively short.

Experimental data on sandblasting are meager and difficult to apply to rocks whose hardness and durability are unsuited to the limited exposure possible in laboratory procedures. Fortunately, however, some deserts and beaches of the world are strewn with wind-carved stones and boulders. Conditions of their occurrence show clearly that they have been shaped by wind action in the interval since Pleistocene glaciation, a lapse of time which geologists seem to agree was shorter than any one of the glacial ages, and under conditions of attack probably far less rigorous than those that we suspect obtained along the periphery of the Quaternary ice sheets.

Evidence is accumulating from many localities, furthermore, that ventifacts exactly comparable with the one illustrated by Leverett were produced and buried during even a relatively small portion of a single glacial subage. One notable example of this should suffice to illustrate the point.

Kirtley Mather, Richard P. Goldthwait, and L. R. Thiesmeyer[8]

[7] *Op. cit.*, p. 548 and Fig. 1.

[8] "Pleistocene Geology of Western Cape Cod, Massachusetts," *Bull. Geol. Soc. Amer.*, Vol. LIII (1942), pp. 1163–73.

called attention to quartzite and granite boulders strongly modified by wind action that are embedded in till deposits and in undisturbed gravel layers of Cape Cod. Thousands of these stones were carried to their present positions, carved by the wind, and then covered with outwash during construction of a single outwash plain. This landform (the Mashpee pitted plain) represents only a minor fraction of the recessional history of Wisconsin ice across New England.[9]

Such impelling evidences urge us to modify our estimates either of the time occupied by Pleistocene glaciation or of the rapidity with which some geologic processes can operate under the special conditions of an ice age.

Hobbs presents an excellent description of conditions prevailing in the zone extramarginal to the Greenland ice sheet.[10] From this he argues that notably "etched" boulders owe their modification to sandblasting by anticyclonic winds. He states that such action is almost constant during a large part of the year and implies that the marked degree of wastage noted on these boulders has been produced within the last part of postglacial or recent time. Indeed, if this were not so, it is unlikely that many of them would now be exposed to view. They would long since have been buried in the continual construction of outwash deposits which he has so vividly described.

Hobbs's[11] account of details in the building of an outwash plain is a distinct contribution to understanding and interpretation of phenomena continually encountered in the study of earlier glacial deposits. The writers would echo his plea that glaciated areas of North America be restudied in the light of modern knowledge concerning extramarginal conditions near continental glaciers. They find some difficulty, however, in accepting as true ventifacts boulders such as he pictures[12] without further description of the evidence for wind-etching.

We submit that an etched surface or "stone-lattice" appearance is not *of itself* necessarily indicative of wind sculpture, even though the material in the recessed portions may appear rather fresh. Hobbs's photographs do not show, and he does not mention, such important features as preservation of polish or luster on the protruding surfaces

[9] *Ibid.*, p. 1152 and p. 1162, Fig. 3.

[10] *Op. cit.*, p. 557.

[11] *Loc. cit.*

[12] *Ibid.*, p. 558, Fig. 1.

of dikes and veins, the development of cuspate furrows, pits, flutings, or even poorly developed facets on the more resistant dikes. Such minor irregularities have long been recognized as characteristic of wind-sculptured stones. Descriptions and photographs of them are available in many papers, including several of recent date.[13] Our experience with wind-modified stones indicates that these are the *most conclusive* evidences of wind abrasion and are common on quartzitic and granitic ventifacts.

On boulders of the dimensions Hobbs has pictured, stones that must have had protruding edges and surfaces facing many directions and open to attack as the depth of wastage increased, surely some beveling of exposed corners and edges of the dikes, some minor fluting of nonuniform parts of the resistant dike material, or some polishing of dike walls seems inevitable under attack by wind-driven sand. Perhaps Professor Hobbs will be prompted to supply information on these details, but until then the writers feel constrained to withhold recognition of such boulders as unquestioned ventifacts.

Differences in use of the term "etched" may lead to confusion. The writers agree with J Harlen Bretz[14] in considering that in a sense "etching is a generic term for minor concavities and reductions and that pitting, grooving, furrowing, and fluting are species of the genus." Hobbs apparently uses "etched" to describe boulders on which the differential wastage has been so pronounced that the periphery of the weaker portion is reduced to half its original dimension. It seems unlikely that sandblasting would have accomplished this without notable reduction and obvious marking of the protruding parts. Consequently, one questions not only the appropriateness of the term "etched" for such boulders but also the conclusion that sandblasting was the sole agent responsible for their present configuration.

Let it be clearly understood that we do not question the efficacy of wind to seek out and reduce less resistant portions of a rock of any dimensions. We have indeed seen too many splendid examples of just

[13] Thiesmeyer and Digman, *op. cit.*, pp. 180–84; Mather, Goldthwait, and Thiesmeyer, *op. cit.*, pp. 1167–70 and Pls. 3, 4, 5, 6, 7; Thiesmeyer, *Science*, Vol. XCVI (1942), p. 244.

[14] Personal communication.

such action on stones varying from ½ inch to 40 feet in diameter; but always the polishing, fluting, beveling of edges, formation of cusps on protruding dike walls, and characteristic greasy feel of a sandblasted surface were obvious, unless modified or destroyed subsequent to sandblasting. Moreover, we do not question that myriads of true ventifacts are to be found around the Greenland glacier and that Hobbs may have observed thousands of them. We do suspect, however, that among the boulders in this peripheral zone are many like those under discussion on which the polish, furrows, pits, and flutings, if they ever did exist, have been destroyed by subsequent solution, spalling, or some weathering process. Mechanical weathering that predominates in periglacial regions undoubtedly has a particularly noticeable effect on stones of nonuniform textural and structural characteristics. It seems hazardous, therefore, to assume an earlier wind action merely because a stone happens to be as deeply etched as are other unquestioned ventifacts in the same area or because its recessed portions appear decidedly fresh.

The authors have also seen scattered over glaciated areas numerous "etched" boulders of the type Hobbs pictures; but the evidences of wind scour enumerated above are completely lacking on most of them. An excellent example is the 9-foot striated "stone-lattice" boulder illustrated by C. S. Gwynne,[15] who also attributed its striking surface configuration to wind sculpture. Last winter the senior author visited this remarkable boulder with Gwynne and called his attention to the absence of those telltale minor features that are so universally found on the wind-etched stones described by many writers from both ancient and modern deposits. It was also emphasized that complete preservation of striae on the top surfaces of the dikes, while wind-driven sand was reducing the surrounding material a full 2 inches, would be truly remarkable. As can be seen on Gwynne's photograph, outside portions of the dikes that do not now carry the striae have clearly been roughened in postglacial weathering. Since these minor irregularities are fresh but carry no sign of polishing or smoothing to indicate that they are modifications developed in a sandblast, the writers would attribute them rather to

[15] "Etched Boulder at Ames, Iowa," *Jour. Geomorph.*, Vol. IV (1941), pp. 322–24, and Fig. 1.

pitting and miniature spalling that has left little evidence of chemical attack. May it not be that the generally coarser-textured mafic wallrock was more vulnerable to such disintegration and retreated even farther than the granitic and aplitic dikes during the same time interval and by the same processes? Rainwash alone would be competent to carry off the loosened material almost as rapidly as it formed.

These differences of interpretation should not, of course, minimize in any way the contributions both Gwynne and Hobbs have made by directing attention to some of the finest examples yet found of these anomalous stones whose etching is most readily but cannot be safely ascribed to wind without corroborative evidence. Further study and clarification of the matter are considered important because sweeping interpretations of glacial geology may be based on an erroneous understanding of criteria diagnostic of wind sculpture. We invite discussion, therefore, by others whose experience with sandblasting may add light to a subject that has already become even more controversial in correspondence than in publications.

ACKNOWLEDGMENTS.—In final preparation of the manuscript the writers have been aided by comments and suggestions of R. T. Chamberlin and J H. Bretz, of the University of Chicago, and R. F. Flint, of Yale University.

## NOTE BY FRANK LEVERETT

As pointed out by Thiesmeyer, the shaping of such a boulder as the white quartzite in Figure 1 of my paper[1] may not require a longer period than was covered by the anticyclonic winds from the Iowan ice sheet. It was probably longer than that in which a similar shaping of boulders was effected in southeastern Massachusetts in a small part of the recession of the Wisconsin ice sheet there. In my paper (p. 549) I stated that the relative effectiveness of wind work and slope wash in this district remains to be determined.

My statement on page 554 that the blue loess was for a considerable time a *surface deposit* carrying a growth of vegetation I now think is open to question. W. H. Norton's view seems to me more likely. In his Linn County report[2] and in his Scott County report[3] the presence of a basal ashen or drab loess with ferruginous tubelets is noted, and in the latter report a band of ocherous material that separates the drab loess from the main body of loess above, concerning which he said: "This ferretto is not taken to indicate an old weathered surface, but merely the place of deposit of iron salts by the movement of ground water in the entire mass of the loess."

As the main loess is readily penetrable by roots the trees may send roots through it into the damp ashen loess beneath. Oxidation has completely destroyed all traces of roots in the porous loess. This leads me to observe that, as far as I can recall, I have never found woody material preserved in *oxidized* till. It seems to be confined to the unoxidized zone in all the drifts, from the Nebraskan to the late Wisconsin. It also is preserved with other vegetation in *buried* peat deposits.

The Iowan drift of Iowa and Minnesota I now regard as a Keewatin product of Early Wisconsin rather than of Late Illinoian age. It appears to correlate closely with the Labradorian Early

[1] "Wind Work Accompanying or Following the Iowan Glaciation," *Jour. Geol.*, Vol. L (1942), pp. 548–55.

[2] *Iowa Geol. Survey*, Vol. IV (1895), pp. 173–74.

[3] *Ibid.*, Vol. IX (1899), pp. 484–85.

Wisconsin of northern Illinois. The drift in the lowland of the Green River lobe, as shown by tests made by Dr. M. M. Leighton,[4] has had leaching of similar depth to that of the Iowan in Iowa, there being 5.7 feet on the Green River drift and 5.2 feet on the Iowa Iowan. Furthermore, the two lobes seem to have nearly come in contact in the Green River lowland and because of this have filled it with sand in large amount. It may be that the basal sand so common on the borders of the Iowa Iowan and in some of the paha ridges is referable to this clogging.

Leighton has correlated the Early Wisconsin of northern Illinois with the Shelbyville and Champaign systems of Early Wisconsin moraines. There is thus a possibility, if not a probability, that the Tazewell substage includes the Iowan.

A further note seems called for on the relation of the loess to anticyclonic, as distinct from planetary wind action. Hobbs[5] has suggested that anticyclonic winds from the Late Wisconsin–Des Moines lobe may have swept the Iowan till on its east side in Worth and Cerro Gordo counties so strongly as to prevent the retention of loess. But in Mitchell County, the second county to the east, Calvin,[6] under the topic "Supra-Iowan loess," reported a loess deposit less than 1 foot in thickness. There is a supra-Iowan loess farther east covering the pebble band on the Iowan till to a depth of 2–4 feet, which now seems likely to be of Late Wisconsin age. West of the Des Moines lobe the Iowan drift has a scanty loess cover which may have drifted in from the thick loess of the Missouri River bluffs and thus have no definite time of deposition.

[4] "Differentiation of the Drift Sheets of Northwestern Illinois," *Jour. Geol.*, Vol. XXXI (1923), p. 271.

[5] Personal communication.

[6] *Iowa Geol. Surv.*, Vol. XIII (1902), pp. 329–30.

# REVIEWS

*Dana's Manual of Mineralogy*. 15th ed. Revised by CORNELIUS S. HURLBUT, JR. New York: John Wiley & Sons, Inc., 1941. Pp. x+480; figs. 436; pls. 20. $4.00.

The first edition of this work was published in 1848; a fourth and last edition by J. D. Dana appeared in 1887. The book was practically rewritten by W. E. Ford in 1912 (13th ed.) and revised by him in 1928. The present volume marks the end of the Dana-Yale tradition, but Dana-Wiley march on.

The general plan and level of the book are unchanged. The format and type are larger, there is less fine print, and stiff covers replace the flexible ones. The halftones (plates) are new and are good; the colored frontispiece is most attractive.

The first sixty-five pages deal with crystallography, which here means "symmetry," "systems," "indices," and "forms." No real use is made of crystal angles or axial ratios. Unfortunately the symmetry symbolism adopted is not the simple form internationally agreed upon. While composite symmetry is introduced (p. 10), it is not employed in the description of the chalcopyrite class, which thus makes it seem to have lower symmetry than the barite class; fifteen of the thirty-two classes are briefly described. The idea of zone symbols is introduced, but in erroneous fashion. This has perhaps led to the confusion over monoclinic twin axis and twin plane in the new six-page section devoted to twin crystals.

After physical mineralogy (no description of the polarizing microscope, etc.) appears chemical mineralogy (pp. 87–130). The atomic weights are given in tabular form, but there is no periodic table. There are said to be ten chemical classes, which is in agreement with the Table of Contents, but on page 132 eleven are listed. Isomorphism is defined as a combination of isostructure and mixed crystals, and may be either partial or complete. Is our most abundant example of mixed crystals—the plagioclases—known to be isostructural? A brief new section on simple flame spectroscopy should be of value. The scheme of blowpipe analysis at the end of this chapter approaches what might be worked out in a chemical laboratory.

On pages 131–353 appear the descriptions of 129 commoner minerals

and 64 rarer ones; some 120 other minerals are listed under the heading "similar species." Another new heading introduced is "diagnostic features." Borates (and nitrates) are grouped with the carbonates, columbite-tantalite with the oxides, and uraninite with the tungstates-molybdates. The silicates come last and start with quartz and other network structures.

The section on the occurrence of minerals (pp. 354–75) has been much improved, but even under the sedimentary rocks one of our most valuable mineral products—coal—is omitted. A section on mineral uses (pp. 376–409) replaces the listing according to elements and Appendix II of the old edition and is very creditably done. The determinative tables are changed only in detail; emery should be added on page 423, chalk on page 429. It is unfortunate that such a widespread mineral as glauconite is omitted. The tables lack an index. They are followed by a specific-gravity table, replacing that on crystal systems of the last edition. There are two indexes, the latter listing a few data on mineral species. There is thus no index to the minerals given in the occurrence or uses sections.

It should not be inferred from the above that the book has not been greatly improved; quite the contrary. It is one of the best books available at its level. Those who have used it in the past will no doubt continue to do so with thanks to the reviser. Others should carefully examine its many modern aspects.

D. J. F.

---

*Possible Future Oil Provinces of the United States and Canada.* Edited by A. I. LEVORSEN. Tulsa: American Association of Petroleum Geologists, 1941. Pp. 154; figs. 83. $1.50.

In view of the present trend in international affairs and of the continued leadership in oil production which North America must maintain, this symposium by the A.A.P.G. Research Committee could hardly have appeared at a more opportune time. Under the leadership of Mr. Levorsen, local groups in the United States and Canada cast up the balance sheet of oil—not present reserves but future possibilities. The net result is heartening not only because of the optimistic picture it paints but also because it demonstrates how effective co-operative research can be in the attack on such fundamental problems as the one here set before geologists.

In the Foreword, which outlines the problem and sets its boundaries, Mr. Levorsen describes the several criteria which were used in evaluating

the possibilities for oil in new regions. These "criteria of an undiscovered oil province" involve (1) the volume and character of the sediments; (2) evidences of oil and gas; (3) unconformities; and (4) wedge belts of porosity.

Following the Foreword are sections devoted to nine individual provinces, ranging from Alaska and western Canada along the Pacific Coast, through the Rocky Mountains, the midcontinent and west Texas; and from eastern Canada through the Appalachian region to the southeastern United States. Each of these sections is treated in a parallel manner. The four criteria are applied and evaluated, and the discussion includes a wealth of material on stratigraphic sections, basins of sedimentation, structures, and the like, which make the book a valuable reference in regional geology as well as in the particular domain for which it was written. Each province is illustrated by maps and sections. One item which will be appreciated by all readers is the standardized set of map symbols used throughout. The maps themselves are professionally drawn and show adequate detail without cluttering the essential picture with minor features. In fact, throughout the entire book one has the feeling that the essence of the subject has been included without extraneous detail or fancy trimmings. The typography and illustrations are of the uniform excellent quality which A.A.P.G. publications always present.

It would be unfair to the reader to summarize the oil possibilities of each province here. As most geologists know, the material was included in the August, 1941, issue of the *Bulletin*. Its appearance as a separate volume has the advantages of compactness and unity. All petroleum geologists must have a copy, and every general geologist ought to have one. Mr. Levorsen and his co-workers are to be complimented on a first-rate job which sets a precedent for conciseness and clarity.

W. C. KRUMBEIN

---

*Coal Paleobotany*. By REINHARDT THIESSEN and GEORGE C. SPRUNK. Bureau of Mines Technical Paper 631. Washington, D.C., 1941. Pp. iv+56; figs. 44. $0.15.

The introduction to this short paper states that the main object of the authors is to bring to the notice of paleobotanists the fact that coal contains a wealth of fossil material in a good state of preservation. The data in the paper are a by-product of petrographic studies and as such present no detailed systematic results.

Three types of plants may be distinguished in Paleozoic coals: coniferous-like, cycadophyte, and lycopod. One of these three types is commonly dominant in a given layer or bed, with the other two types present in small quantities.

The conifer-like plants, the Cordaitales, are represented by fragments of xylem, bark, and leaves and by resinous inclusions. Remnants of collapsed stems and of periderm may be identified as "lycopod" in nature. Cycadophytes are present as pieces of xylem, cortex, leaves, petiole, rachis, pinnules, pollen, resinous cell contents, and particularly by the mucilaginous contents of the gum ducts.

The paper is exceptionally well illustrated by photographs of thin sections of coal.

ERNEST P. DU BOIS

---

*Small Foraminifera from the Late Tertiary of the Nederlands East Indies.* By L. W. LEROY. (Colorado School of Mines Quarterly, Vol. XXXVI, No. 1.) Golden, Colo., 1941. Pp. 132; figs. 25. $2.00.

Published information on small Foraminifera of the Tertiary of the Netherlands East Indies has been rather scanty, and much of it is in sources not readily available to workers in this country. Three faunas are described in the three papers which constitute this number of the *Quarterly*. The first is from East Borneo with 152 species described and illustrated. This fauna, which is provisionally assigned to the upper part of the Miocene, is widely distributed over the Indo-Pacific region. Characterized by preponderance of such forms as *Globigerina*, *Globigerinoides*, *Nodosaria*, *Eponoides*, and *Bolivinita*, it gives the impression of having lived in a moderately deep offshore environment. The second paper deals with and illustrates 128 species of small Foraminifera from Siberoet Island, off the west coast of Sumatra. As an assemblage this fauna is almost identical with the East Borneo one; therefore, an age relationship is suggested. The third paper records 47 species from the type locality of the Bantamien substage in west Java. This fauna is a characteristic shallow-water marine facies, closely related to living forms, and is provisionally considered to be upper Pliocene in age.

C. W. STERNBERG

---

*Introduction to Physical Geology.* By W. J. MILLER. 4th ed. New York: D. Van Nostrand Co., 1941. Pp. xi+465, figs. 397.

The success of earlier editions of this text has well warranted the appearance of a new revision. Somewhat more simplified than many other

standard texts of physical geology, it very satisfactorily fulfils the function of presenting this subject to the college Freshman.

The most notable changes from the previous edition are the addition of new figures and diagrams, the re-writing of certain portions, and the revision of the statistical material in the chapter on "Economic Geology."

ERNEST P. DU BOIS

---

*A Middle Eocene Flora from the Central Sierra Nevada.* By HARRY D. MACGINITIE. Carnegie Institution of Washington Publication 534. Washington, 1941. Pp. 178; pls. 47. Paper $2.00; cloth $2.50.

This report is chiefly concerned with the flora of the early Tertiary Chalk Bluff deposits found along a part of an ancient river channel in Placer and Nevada counties, California. In age the deposit is equivalent to the Ione and Capay.

The fossil flora is distributed in 20 orders, 44 families, 66 genera, and 77 species. Fifty of the species are new or are established as new combinations. Trees form 54 per cent, shrubs 36 per cent, and vines 10 per cent of the composition. This tree-shrub ratio approximates that found in living tropical forests.

The species represented may be divided into several groups, which can be related to living forms in eastern Mexico and Central America, to forms in subtropical southeastern Asia, and to forms living in the warm-temperate regions of southeastern Asia and southeastern United States. These relationships indicate a humid, subtropical climate.

The systematic section of the report is well done. The treatment of each species includes synonymy, description, discussion, and notes on its occurrence. Excellent plates are used to illustrate each form.

ERNEST P. DU BOIS

# INDEX TO VOLUME L


Abrasion following wind scouring, Arnott moraine, Wisconsin (L. R. Thiesmeyer and R. E. Digman), 184

Adamellite group of intrusives about Nain, Labrador (E. P. Wheeler, 2nd), 619

Adsorbed cations, influence of, on water film (R. E. Grim), 271

Adsorptive properties of clay minerals (R. E. Grim), 252

Age of Asotin stage, Snake River Canyon, Idaho (R. L. Lupher and W. C. Warren), 878
relations of anorthositic rocks, Nain, Labrador (E. P. Wheeler, 2nd), 632

*Agents for transporting sediments, density currents as: studies for students* (H. S. Bell), 512

*Agriculture, modern clay researches in relation to* (W. P. Kelley), 307

Alden, W. C. Review of The last million years: a history of the Pleistocene in North America. By A. P. Coleman. Edited by George F. Kay, 331

Alkali feldspars in Tasmanian dolerites (A. B. Edwards), 590

Alkalic rocks, origin of, in Poohbah Lake area, Ontario (C. C. Allen), 148
syenites in Poohbah Lake area, Ontario (C. C. Allen), 143

Allen, C. C. *The maligniles of Poohbah Lake, Ontario*, 134

Allensville conglomerate member, Pretty Run sandstone facies (F. T. Holden), 58

Allophane (R. E. Grim), 234

American influence in Canadian mining. By E. S. Moore. Review by E. S. Bastin, 218

*Amphibian, Edops, a primitive rhachitomous, from the Texas red beds* (A. S. Romer and R. V. Witter), 925

Amphibole in Tasmanian dolerites (A. B. Edwards), 592

Analyses of rocks from Poohbah Lake, Ontario (C. C. Allen), 146

Annual reports of the Iowa Geological Survey, 1934–1939, with accompanying papers. Review by R. T. Chamberlin, 918

*Anorthosite and associated rocks about Nain, Labrador* (E. P. Wheeler, 2nd), 611

Anorthositic gabbro-diorite group near Nain, Labrador (E. P. Wheeler, 2nd), 613

Antevs, E. Cited on stratigraphy of Great Lakes region (R. F. Flint), 574

Apatite in Tasmanian dolerites (A. B. Edwards), 593

Aplite in Poohbah Lake area, Ontario (C. C. Allen), 145

*Appalachian physiography, a study in* (Karl Ver Steeg), 504

*Appalachians, structure of Little North Mountain of the north-central* (A. W. Giles), 961

Appendicular skeleton of Edops, Texas red beds (A. S. Romer and R. V. Witter), 953

*Applications of modern clay research in ceramics* (F. H. Norton), 320
*of modern clay researches in construction engineering* (H. F. Winterkorn), 291

Arctic glacial research (R. F. Flint), 577

Argillaceous materials, miscellaneous (R. E. Grim), 261

*Arizona, multiple Pleistocene glaciation on San Francisco Mountain* (R. P. Sharp), 481

Armstrong member, River Styx conglomerate facies, Ohio (F. T. Holden), 50
sandstone member, Killbuck shale facies, Ohio (F. T. Holden), 49

Arni, P. Sarkl Anadolu ve Mücavir Mintakalarin Tektonik Ana Hatlari: Tektonische Grundzüge Ostanatoliens und benachbarter Gebiete. Review by R. T. Chamberlin, 668

Ashley, G. H. Cited on Appalachian physiography (Karl Ver Steeg), 504 ff.

Asotin Canyon, Idaho (R. L. Lupher and W. C. Warren), 871

stage of Snake River Canyon, Idaho (R. L. Lupher and W. C. Warren), 870
age of (R. L. Lupher and W. C. Warren), 878
physiographic and stratigraphic implications of (R. L. Lupher and W. C. Warren), 880
*stage, the, of the Snake River Canyon near Lewiston, Idaho* (R. L. Lupher and W. C. Warren), 866
*Associated rocks, anorthosite and, about Nain, Labrador* (E. P. Wheeler, 2nd), 611
Atomic structure of pyroxenes in Tasmanian dolerites (A. B. Edwards), 597
Attapulgite (R. E. Grim), 234
structure (R. E. Grim), 249
*Auckland, New Zealand, unusual olivine in basalt near* (J. A. Bartrum), 914
Augite in Tasmanian dolerites (A. B. Edwards), 584
Australia. By Griffith Taylor. Review by C. W. Sternberg, 224
Axial skeleton of Edops, Texas red beds (A. S. Romer and R. V. Witter), 951

Backlund, H. G. Cited on mode of intrusion of deep-seated alkaline bodies (C. C. Allen), 150
Bahr, Adolf. Cited on involution layers (R. P. Sharp), 122
Cited on mechanics of formation of involutions (R. P. Sharp), 130
Baker, George. *Sand stalagmites*, 662
Banded and nonbanded coals (G. H. Cady), 339
Bannock volcanic formation, Idaho (J. C. Ludlum), 88
Barrell, Joseph. Cited on Elkhorn Mining District, Montana (C. C. Allen), 142
Bars, the building of (O. F. Evans), 849
*spits, and related structures, the origin of* (O. F. Evans), 846
Bartrum, J. A. *Unusual olivine in basalt near Auckland, New Zealand*, 914
*Basalt, unusual olivine in, near Auckland, New Zealand* (J. A. Bartrum), 914
Base exchange and minerals of the montmorillonite group (S. B. Hendricks), 285
Base-exchange capacity of clay minerals (R. E. Grim), 250
material in soils (W. P. Kelley), 311
Bastin, E. S. Review of American influence in Canadian mining. By E. S. Moore, 218
Baver, L. D. Soil physics. Review by W. C. Krumbein, 669
Bedford formation, Ohio (F. T. Holden), 34
Behavior of density currents (H. S. Bell), 528
Bell, Hugh Stevens. *Density currents as agents for transporting sediments: studies for students*, 512
Berea formation, Ohio (F. T. Holden), 38
Berne conglomerate member, Pretty Run sandstone facies, Ohio (F. T. Holden), 55
Binary system $NaAlSiO_4$-$CaSiO_3$ (W. R. Foster), 158
$NaAlSiO_4$-$NaAlSi_3O_8$ (W. R. Foster), 157
Biotite in Tasmanian dolerites (A. B. Edwards), 591
Birch, Francis, *et al.* Handbook of physical constants. Review by R. T. Chamberlin, 670
Bituminous coals, types of, on basis of megascopic criteria (G. H. Cady), 339
Black Hand conglomerate member, Hocking Valley facies, Ohio (F. T. Holden), 46
conglomerate member, Toboso facies, Ohio (F. T. Holden), 48
sandstone member, River Styx conglomerate facies, Ohio (F. T. Holden), 50
shale member, Killbuck shale facies, Ohio (F. T. Holden), 49
siltstone member, Granville shale facies (F. T. Holden), 46
Blackrock limestone, Pocatello, Idaho (J. C. Ludlum), 92
Blue Mounds region, Wisconsin (J H. Bretz), 783
Blytt-Sernander hypothesis, a climatic sequence based upon peat layers and plant fossils (W. S. Cooper), 983
*Botanical science, contributions of, to the knowledge of postglacial climates* (W. S. Cooper), 981
Bowen, N. L. Cited on evaluation of igneous rocks (C. C. Allen), 151
Boxwork in caves (J H. Bretz), 733
Branson, Carl C. Review of Wissenschaftliche Ergebnisse der Nieder-

ländischen Expeditionen in den Karakorum und die Angrenzenden Gebiete 1922, 1925, 1929–30, und 1935 herausgegeben von Dr. Ph. C. Visser und Jenny Visser-Hooft. By Rudolf Wyss, 109

Breccia, chemical analysis of, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 17
*at Sudbury, Ontario* (H. W. Fairbairn and G. M. Robson), 1

Breccias, classification of, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 5
other, of Sudbury, Ontario, type (H. W. Fairbairn and G. M. Robson), 32

Bretz, J Harlen. Cited on origin of Mima mounds, Washington (W. W. Dalquest and V. B. Scheffer), 82
Earth sciences. Review by A. C. Swinnerton, 110
*Vadose and phreatic features of limestone caverns*, 675

Bright coal (C. E. Marshall), 387

Bucher, Walter H. Review of Report of the Subcommittee on the Ecology of Marine Organisms, 922

Buena Vista sandstone member, Scioto Valley shale facies, Ohio (F. T. Holden), 60
Vanceburg siltstone facies, Ohio (F. T. Holden), 62

Burbank member, Killbuck shale facies, Ohio (F. T. Holden), 49

Butts, C., and R. S. Edmundson. Cited on geology of Little North Mountain, Appalachians (A. W. Giles), 963 ff.

Byer sandstone member, Pretty Run facies, Ohio (R. T. Holden), 56

Cady, Gilbert H. *Modern concepts of the physical constitution of coal*, 337

Cain, S. A. Cited on pollen analysis as a paleo-ecological research method (W. S. Cooper), 984

Calcite in Tasmanian dolerites (A. B. Edwards), 592

Cambrian (?) and post-Cambrian deposits, Grand Canyon, Arizona (E. T. Schenk and H. E. Wheeler), 896
*sequence in western Grand Canyon, Arizona* (E. T. Schenk and H. E. Wheeler), 882

Cameron Cave, Missouri, the network of (J H. Bretz), 700
vadose alteration of phreatic passages in (J H. Bretz), 743

Campanian sediments, Palestine (H. A. Lowenstam), 840

Cannel (E. C. Dapples), 446
and boghead coals (G. C. Sprunk), 420

Cannels (G. H. Cady), 346

*Canyon, the Snake River, near Lewiston, Idaho, the Asotin stage of* (R. L. Lupher and W. C. Warren), 866
*western Grand, Arizona, Cambrian sequence in* (E. T. Schenk and H. E. Wheeler), 882

*Carbonization, chemical, and hydrogenation, properties, influence of physical constitution of coal upon its* (G. C. Sprunk), 411

Carlsbad Cavern, New Mexico, floor pockets of (J H. Bretz), 711
and Slaughter Canyon Caverns, New Mexico, history of (J H. Bretz), 777

Carnegieite (W. R. Foster), 156

Casting process of molding ceramics (F. H. Norton), 325

Castings slips (F. H. Norton), 323

Catalogue, a, of the foraminifera. By Brooks F. Ellis and Angelina R. Messina. Review by Carey Croneis, 560

Cation replaceability of clay minerals (R. E. Grim), 254

Cave chambers extended along the dip (J H. Bretz), 755
solution related to stylolite seams (J H. Bretz), 735

Cavern making in erosion cycle (J H. Bretz), 782

*Caverns, vadose and phreatic features of limestone* (J H. Bretz), 675

Caves in phreatic zone today (J H. Bretz), 807
in tilted formations (J H. Bretz), 754

Ceiling pockets in caves (J H. Bretz), 711
tubes and half-tubes in caves (J H. Bretz), 717

Cenomanian rocks, Eastern Nazareth Mountains, Palestine (H. A. Lowenstam), 819

Ceramic molding methods (F. H. Norton), 324

*Ceramics, applications of modern clay research in* (F. H. Norton), 320
Chamberlin, Rollin T. Review of Annual reports of the Iowa Geological Survey, 1934–1939, with accompanying papers, 918
Review of Crater Lake; the story of its origin. By Howel Williams, 220
Review of Handbook of physical constants. Edited by Francis Birch *et al.*, 670
Review of Outlines of structural geology. By E. Sherbon Hills, 923
Review of Sarkl Anadolu ve Mücavir Mintakalarin Tektonik Ana Hatlari: Tektonische Grundzüge Ostanatoliens und benachbarter Gebiete. By P. Arni, 668
Review of The structure of the Kejser Franz Josephs Fjord region, northeast Greenland. By N. E. Odell, 334
Chambers, cave along the strike (J H. Bretz), 759
Chaney, R. W. A Miocene flora from Shantung Province, China (E. P. Du Bois), 223
*Characteristics, chemical, relation of the physical constitution of coal to its* (H. H. Lowry), 357
Chemical analyses of types of coal (G. C. Sprunk), 415
analysis of breccia, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 24
*characteristics, relation of the physical constitution of coal to its* (H. H. Lowry), 357
*hydrogenation, and carbonization properties, influence of physical constitution of coal upon its* (G. C. Sprunk), 411
individuality of the physical components of coal (G. H. Cady), 353
relations of Poohbah stock, Ontario (C. C. Allen), 145
Chisholm shale, Grand Canyon, Arizona (E. T. Schenk and H. E. Wheeler), 892
Chlorite in Tasmanian dolerites (A. B. Edwards), 591
Chloritic mica (R. E. Grim), 235
structure (R. E. Grim), 250
Churn Creek member, Vanceburg siltstone facies, Ohio (F. T. Holden), 63
Clarain (G. H. Cady), 345
(E. C. Dapples), 445
Classification of breccias, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 5
of coals, technique of (G. H. Cady), 350
and composition of clay minerals (R. E. Grim), 231
*physical constitution of coal as related to description and* (E. C. Dapples), 437
Clay filling, the epoch of, in cave history (J H. Bretz), 773
*materials, modern concepts of* (R. E. Grim), 225
mineral, types of (F. H. Norton), 329
mineral concept (R. E. Grim), 228
minerals—base exchange (R. E. Grim), 250
minerals, classification and composition (R. E. Grim), 231
minerals, formation of (W. P. Kelley), 314
minerals—reduction of particle size on agitation in water (R. E. Grim), 262
minerals of soils (W. P. Kelley), 312
minerals in soils, importance of (W. P. Kelley), 317
*research, modern, in ceramics, applications of* (F. H. Norton), 320
*researches, applications of modern, in construction engineering* (H. F. Winterkorn), 291
*researches, modern, in relation to agriculture* (W. P. Kelley), 307
variables, control of, in clay processes (F. H. Norton), 330
variables in, that influence the molding properties (F. H. Norton), 328
-water system (R. E. Grim), 263
system (F. H. Norton), 320
Clays and their treatment (F. H. Norton), 326
*Climates, postglacial, contributions of botanical science to the knowledge of* (W. S. Cooper), 981
Coal, hydrogenation properties of types of, and their constituents (G. C. Sprunk), 429
*influence of physical constitution of, upon its chemical, hydrogenation, and carbonization properties* (G. C. Sprunk), 411
*modern conceptions of the physical constitution of, and related research in Great Britain* (C. E. Marshall), 385
*modern concepts of the physical constitution of* (G. H. Cady), 337

paleobotany. By Reinhardt Thiessen and George C. Sprunk. Review by E. P. Du Bois, 1005
petrographic types of (G. C. Sprunk), 412
*physical constitution of, as related to coal description and classification* (E. C. Dapples), 437
*preparation, practical significance of the physical constitution of coal in* (L. C. McCabe), 406
processing (G. H. Cady), 355
rank and physical constitution of (C. E. Marshall), 401
rank and type of (G. C. Sprunk), 412
study, technique of (G. H. Cady), 349
types and constituents (C. E. Marshall), 386
types and constituents, petrological classification of (C. E. Marshall), 395
types, primary (E. C. Dapples), 439
varieties (G. H. Cady), 338

Cohesion, friction, and plasticity (H. F. Winterkorn), 298

Coking tests, correlation of small-scale laboratory, with microscopic composition of coal (G. C. Sprunk), 421

Coleman, A. P. The last million years: a history of the Pleistocene in North America. Edited by George F. Kay. Review by W. C. Alden, 331
Cited on age of sedimentary rocks, Nain, Labrador (E. P. Wheeler, 2nd), 633

Composite coals (G. H. Cady), 346

Composition of clay materials, concepts of (R. E. Grim), 227
of sand stalagmites, Victoria, Australia (George Baker), 664

*Compression creep of rubber and rock* (J. S. De Lury), 189

*Conceptions, modern, of the physical constitution of coal and related research in Great Britain* (C. E. Marshall), 385

*Concepts, modern, of clay materials* (R. E. Grim), 225
*modern, of the physical constitution of coal* (G. H. Cady), 337

Concretions, description of, in shale member of Pottsville, Georgia (J. W. Sullivan), 210
*an occurrence of, in the Pottsville of Georgia* (J. W. Sullivan), 209

*Conjugate faulting, the genesis of, in the Kern River salient* (L. E. Nugent, Jr.), 900

Constituents, minor, of Tasmanian dolerites (A. B. Edwards), 590

*Constitution of coal, influence of, upon its chemical, hydrogenation, and carbonization properties* (G. C. Sprunk), 411
*of coal, modern conceptions of the physical, and related research in Great Britain* (C. E. Marshall), 385
*of coal, modern concepts of the physical* (G. H. Cady), 337
*of coal, practical significance of the physical, in coal preparation* (L. C. McCabe), 406
*of coal, relation of the physical, to its chemical characteristics* (H. H. Lowry), 357
*physical, of coal as related to coal description and classification* (E. C. Dapples), 437

*Construction engineering, applications of modern clay researches in* (H. F. Winterkorn), 291

Contact breccia, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 13

*Continental glaciers, wind—the dominant transportation agent within extramarginal zones to* (W. H. Hobbs), 556

*Contrasts, regional, in torrential rainfalls help to explain regional contrasts in erosion* (S. S. Visher), 96

*Contributions of botanical science to the knowledge of postglacial climates* (W. S. Cooper), 981

Convection currents as cause of deformation (R. P. Sharp), 126

Cook, Kenneth L. Review of Temperature: its measure and control in science and industry. By various authors, 221

Cooper, William S. *Contributions of botanical science to the knowledge of postglacial climates*, 981

Crater Lake: the story of its origin. By Howel Williams. Review by R. T. Chamberlin, 220

*Creep, compression, of rubber and rock* (J. S. De Lury), 189

Cretaceous deposits in Eastern Nazareth Mountains, Palestine (H. A. Lowenstam), 814
history, Eastern Nazareth Mountains, Palestine (H. A. Lowenstam), 844

Criteria for recognizing ventifacts, Wisconsin (L. R. Thiesmeyer and R. E. Digman), 180

Croneis, Carey. Review of A Catalogue of the foraminifera. By Brooks F. Ellis and Angelina R. Messina, 560
Review of The new systematics. By Julian Huxley (ed.), 106

Cross section, vertical, of Berne conglomerate across Toboso conglomerate facies from Ashland County into Licking County, Ohio (F. T. Holden), 57

Crystallinity of soil colloids (W. P. Kelley), 309

Crystallization, courses of, in the system $NaAlSi_3O_8$-$CaSiO_3$-$NaAlSiO_4$ (W. R. Foster), 166
of pyroxenes, Tasmanian dolerites (A. B. Edwards), 593

Cudjo's Cave, Virginia, and its stream (J H. Bretz), 690, 697

Current flow in caves, specific forms and markings recording (J H. Bretz), 720

*Currents, density, as agents for transporting sediments: studies for students* (H. S. Bell), 512

Cuspate bars and looped bars, formation of (O. F. Evans), 859

Cuyahoga formation, Ohio (F. T. Holden), 40

Dake, H. C., and Jack de Ment. Fluorescent light and its applications. Review by D. J. Fisher, 924

Dalquest, Walter W., and Victor B. Scheffer. *The origin of the Mima mounds of western Washington*, 68

Dana's Manual of mineralogy. Revised by Cornelius S. Hurlbut, Jr. Review by D. J. Fisher, 1003

Dapples, E. C. *Physical constitution of coal as related to coal description and classification*, 437

Davis, William Morris. Cited on phreatic origin of caves (J H. Bretz), 675 ff., 808 f.
Cited on two-cycle history of caverns (J H. Bretz), 693, 782
Cited on "water-table stream" (J H. Bretz), 745, 751

Deleveling, Pleistocene (R. F. Flint), 571

De Lury, J. S. *Compression creep of rubber and rock*, 189

De Ment, Jack, and H. C. Dake. Fluorescent light and its applications. Review by D. Jerome Fisher, 924

*Density currents as agents for transporting sediments: studies for students* (H. S. Bell), 512
currents, behavior of (H. S. Bell), 528
currents, origin of (H. S. Bell), 515

Dermal armor of Edops, Texas red beds (A. S. Romer and R. V. Witter), 956

*Description and classification, physical constitution of coal as related to* (E. C. Dapples), 437
of coals (G. H. Cady), 350
of Mima mounds, Washington (W. W. Dalquest and V. B. Scheffer), 69
of periglacial involutions, northeastern Illinois (R. P. Sharp), 119
of ventifacts, Wisconsin (L. R. Thiesmeyer and R. E. Digman), 179

Development of swell and swale pattern in Wisconsin drift plain, Iowa (C. S. Gwynne), 206

Devonian age of Bedford formation, Ohio (F. T. Holden), 34

Differential freezing and thawing and the formation of ground ice (R. P. Sharp), 128
loading as cause of deformation (R. P. Sharp), 127

Differentiation of dolerite magma, Tasmania (A. B. Edwards), 603
*of the dolerites of Tasmania* (A. B. Edwards), I, 451; II, 579

Digman, R. E., and Lincoln R. Thiesmeyer. *Discussion: wind work accompanying and following glaciation*, 995
*Wind-cut stones in Kansan drift of Wisconsin*, 174
Cited on wind-cut stones in Kansan drift of Wisconsin (F. Leverett), 548

Dike rocks in Nain, Labrador, region (E. P. Wheeler, 2nd), 626

*Discussion, a, of the use and meaning of the term "low and ball"* (O. F. Evans), 213
*further, of the term "low and ball"* (F. P. Shepard), 216
*Wind work accompanying and following glaciation* (L. R. Thiesmeyer and R. E. Digman), 995

Distribution of torrential rains in eastern United States (S. S. Visher), 98

Dolerite dikes, Tasmania (A. B. Edwards), 474
magma, Tasmania (A. B. Edwards), 463
sills, Tasmania (A. B. Edwards), 466

*Dolerites, differentiation of the, of Tasmania* (A. B. Edwards), I, 451; II, 579
of Tasmania, intrusion of (A. B. Edwards), 456

Domepits in caves (J H. Bretz), 722

*Dominant transportation agent, the, within extra-marginal zones to continental glaciers—wind* (W. H. Hobbs), 556

Donnay, J. D. H. Review of Initiation à la géologie. By J. W. Laverdière and L. G. Morin, 222

Drift, Kansan, of Wisconsin, wind-cut stones in (L. R. Thiesmeyer and R. E. Digman), 174
*plain, Wisconsin, in Iowa, swell and swale pattern of the Mankato lobe of the* (C. S. Gwynne), 200

Driving force and velocity, relationship between (H. S. Bell), 520

Dry pressing of ceramics (F. H. Norton), 324

Du Bois, E. P. Review of Coal paleobotany. By Reinhardt Thiessen and George C. Sprunk, 1005
Review of Introduction to physical geology. By W. J. Miller, 1006
Review of A Middle Eocene flora from the Central Sierra Nevada. By Harry D. MacGinitie, 1007
Review of A Miocene flora from Shantung Province, China. By R. W. Chaney, 223
Review of The Tertiary foraminifera of Porto Rico. By J. J. Galloway and Caroline E. Hemingway, 335
Review of The Upper Ordovician fauna of Frobisher Bay, Baffin Land. By Sharat Kumar Roy, 924

Dull coal (C. E. Marshall), 394

Dulphides in Tasmanian dolerites (A. B. Edwards), 593

Durain (G. H. Cady), 345
(E. C. Dapples), 442

Eardley, A. J. Interpretation of geologic maps and aerial photos. Review by D. Jerome Fisher, 921

Earth sciences. By J Harlen Bretz. Review by A. C. Swinnerton, 110

*Eastern Nazareth Mountains, Palestine, geology of the,* I (H. A. Lowenstam), 813
United States, distribution of torrential rains in (S. S. Visher), 98

Edmundson, R. S., and C. Butts. Cited on geology of Little North Mountain, Appalachians (A. W. Giles), 963 ff.

Edops, general description of, Texas red beds (A. S. Romer and R. V. Witter), 927
*a primitive rhachitomous amphibian from the Texas red beds* (A. S. Romer and R. V. Witter), 925

Edwards, A. B. *Differentiation of the dolerites of Tasmania,* I, 451; II, 579

Effects of local loading on tilt, Kilauea Volcano, Hawaii (H. H. Waesche), 659

Eiseley, L. C. Cited on pollen analysis and its bearing upon American prehistory (W. S. Cooper), 984

Ellis, Brooks F., and Angelina R. Messina. A catalogue of the foraminifera. Review by Carey Croneis, 560

Endless Caverns, Virginia, crescentic wall niches in (J H. Bretz), 742
pendants of (J H. Bretz), 740

*Engineering, construction, applications of modern clay researches* in (H. F. Winterkorn), 291
soil problems, two major groups of (H. F. Winterkorn), 294
usage of the term "soil" (H. F. Winterkorn), 293

*Erosion, regional contrasts in torrential rainfalls help to explain regional contrasts in* (S. S. Visher), 96

Erosional history, later, of Snake River Canyon, Idaho (R. L. Lupher and W. C. Warren), 877
results of heavy rains in United States (S. S. Visher), 103

Evans, O. F. *A discussion of the use and meaning of the term "low and ball,"* 213
*The origin of spits, bars, and related structures,* 846

Experiments showing compression creep of rubber (J. S. De Lury), 190

*Extramarginal zones to continental glaciers, wind—the dominant transportation agent within* (W. H. Hobbs), 556

Extrusion molding of ceramics (F. H. Norton), 325

Factors of soil formation: a system of quantitative pedology. By Hans Jenny. Review by W. C. Krumbein, 919

Fairbairn, H. W., and G. M. Robson. *Breccia at Sudbury, Ontario*, 1

Fairfield sandstone member, Hocking Valley conglomerate, Ohio (F. T. Holden), 45

Fallen blocks, solution of, in caves (J H. Bretz), 735

Faulting, age of, Kern River region, California (L. E. Nugent, Jr.), 908
*the genesis of subordinate conjugate, in the Kern River salient* (L. E. Nugent, Jr.), 900

Faults, boundary, Kern River region, California (L. E. Nugent, Jr.), 905

Fauna in Cenomanian strata, Eastern Nazareth Mountains, Palestine (H. A. Lowenstam), 829

*Features, vadose and phreatic, of limestone caverns* (J H. Bretz), 675

Field geology. By Frederic H. Lahee. Review by F. J. Pettijohn, 922

Fisher, D. Jerome. Review of Danas' Manual of mineralogy. Revised by Cornelius S. Hurlbut, Jr., 1003
Review of Fluorescent light and its applications. By H. C. Dake and Jack de Ment, 924
Review of Interpretation of geologic maps and aerial photos. By A. J. Eardley, 921

Flint, Richard Foster. *Progress and problems in the North American Pleistocene*, 563

Flocculation, effect of (H. S. Bell), 539

Fluorescent light and its applications. By H. C. Dake and Jack de Ment. Review by D. J. Fisher, 924

Flutes in caves (J H. Bretz), 731

*Formations, pre-Cambrian, at Pocatello, Idaho* (J. C. Ludlum), 85

Fossils, inference from, in interpreting postglacial climates (W. S. Cooper), 981

Foster, Wilfrid R. *The system $NaAlSi_3O_8$-$CaSiO_3$-$NaAlSiO_4$*, 152

Friability of coal constituents (L. C. McCabe), 408

Frood breccia, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 14

Frost action, effects of, on San Francisco Mountain, Arizona (R. P. Sharp), 497

Fusain (G. H. Cady), 344
(E. C. Dapples), 441
(C. E. Marshall), 393

Galloway, J. J., and Caroline E. Hemingway. The Tertiary foraminifera of Porto Rico. Review by E. P. Du Bois, 335

Gardner, J. H. Cited on origin and development of limestone caverns (J H. Bretz), 745, 771

*Genesis, the, of subordinate conjugate faulting in the Kern River salient* (L. E. Nugent, Jr.), 900

Geologic studies in southwestern Kansas. By H. T. U. Smith. Review by C. W. Sternberg, 223

*Geology of the Eastern Nazareth Mountains, Palestine*, I (H. A. Lowenstam), 813
of Poohbah Lake area, Ontario (C. C. Allen), 134
of the Presidential Range. By Richard P. Goldthwait. Review by C. W. Sternberg, 112
the, and ore deposits of north-eastern New Mexico. By George T. Harley. Review by C. W. Sternberg, 334
and soil science (W. P. Kelley), 318

*Georgia, an occurrence of concretions in the Pottsville of* (J. W. Sullivan), 209

Gilbert, G. K. Cited on origin of spits and bars (O. F. Evans), 848

Giles, Albert W. *Structure of Little North Mountain of the north-central Appalachians*, 961

Glacial erosion and glacial deposits (R. F. Flint), 330

Glaciation, causes of (R. F. Flint), 574
*the Iowan, wind work accompanying or following* (F. Leverett), 548
*multiple Pleistocene, on San Francisco Mountain, Arizona* (R. P. Sharp), 481
*wind work accompanying and following: discussion* (L. R. Thiesmeyer and R. E. Digman), 995

Goldthwait, Richard P. Geology of the Presidential Range. Review by C. W. Sternberg, 112

*Grand Canyon, Arizona, Cambrian sequence in western* (E. T. Schenk and H. E. Wheeler), 882

Caverns, Virginia, horizontal chambers of (J H. Bretz), 704
Granite in Poohbah Lake area, Ontario (C. C. Allen), 145
Granville shale facies, Ohio (F. T. Holden), 46
*Great Britain, modern conceptions of the physical constitution of coal and related research in* (C. E. Marshall), 385
Green River, caves west of, Mammoth Cave National Park (J H. Bretz), 771
Grim, Ralph E. *Modern concepts of clay materials*, 225
Ground moraine, swell and swale pattern of, in Iowa (C. S. Gwynne), 202
*tilt at Kilauea Volcano* (H. H. Waesche), 643
Grout, F. F. Cited on Poohbah stock, Ontario (C. C. Allen), 151
Growth of Mima mounds, Washington (W. W. Dalquest and V. B. Scheffer), 77
Gulliver, F. P. Cited on cuspate forelands (O. F. Evans), 847
Gunning's Sugarloaf (A. B. Edwards), 474
Gwynne, Charles S. *Swell and swale pattern of the Mankato lobe of the Wisconsin drift plain in Iowa*, 200

Halloysite (R. E. Grim), 233
structure (R. E. Grim), 245
Handbook of physical constants. Edited by Francis Birch *et al.* Review by R. T. Chamberlin, 670
Harley, George T. The geology and ore deposits of northeastern New Mexico. Review by C. W. Sternberg, 334
Hemingway, Caroline E., and J. J. Galloway. The Tertiary foraminifera of Porto Rico. Review by E. P. Du Bois, 335
Hendricks, Sterling B. *Lattice structure of clay minerals and some properties of clays*, 276
Henley shale facies, Ohio (F. T. Holden), 45
Hills, E. Sherbon. Outlines of structural geology. Review by R. T. Chamberlin, 923
Hobbs, William H. *Wind—the dominant transportation agent within extramarginal zones to continental glaciers*, 556
Hocking Valley conglomerate facies, Ohio (F. T. Holden), 45
Holden, Frederick T. *Lower and Middle Mississippian stratigraphy of Ohio*, 34
Horizontal grooves and ridges on walls of caves in flat-lying beds (J H. Bretz), 721
Hornblende syenites in Poohbah Lake area, Ontario (C. C. Allen), 144
Huxley, Julian (ed.). The new systematics. Review by Carey Croneis, 106
*Hydrogenation, chemical, and carbonization properties, influence of physical constitution of coal upon its* (G. D. Sprunk), 411

Ice-sheet deformation, slow recovery of the earth from (J. S. De Lury), 197
sheets, genesis of (R. F. Flint), 574
shove as cause of deformation (R. P. Sharp), 127
*Idaho, the Asotin stage of the Snake River Canyon near Lewiston* (R. L. Lupher and W. C. Warren), 866
*pre-Cambrian formations at Pocatello* (J. C. Ludlum), 85
Illinoian glaciation, Arizona (R. P. Sharp), 484
*Illinois, periglacial involutions in northeastern* (R. P. Sharp), 113
Illite (R. E. Grim), 231
structure (R. E. Grim), 243
Incised meanders in cave walls and ceilings (J H. Bretz), 720
Initiation à la géologie. By J. W. Laverdière and L. G. Morin, 222
of Mima mounds, Washington (W. W. Dalquest and V. B. Scheffer), 76
Injection breccia, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 14
Interpretation of geologic maps and aerial photos. By J. A. Eardley. Review by D. Jerome Fisher, 921
Intracanyon lavas, Snake River, Idaho (R. L. Lupher and W. C. Warren), 874
Intrastratified clay minerals (R. E. Grim), 237
Introduction to physical geology. By W. J. Miller. Review by E. P. Du Bois, 1006
Involution layers, northeastern Illinois (R. P. Sharp), 124

*Involutions, periglacial, in northeastern Illinois* (R. P. Sharp), 113
*Iowa, swell and swale pattern of the Mankato lobe of the Wisconsin drift plain in* (C. S. Gwynne), 200
*Iowan glaciation, wind work accompanying or following the* (F. Leverett), 548
Wisconsin glaciation, Arizona (R. P. Sharp), 488
Iron ore in Tasmanian dolerites (A. B. Edwards), 592

Janssen, Raymond E. Some fossil plant types of Illinois. Review by C. W. Sternberg, 111
Jenny, Hans. Factors of soil formation: a quantitative pedology. Review by W. C. Krumbein, 919
Johannsen, Albert. Cited on malignites of Poohbah Lake area, Ontario (C. C. Allen), 137
Johnson, D. W. Cited on spits and bars (O. F. Evans), 847 ff.
Joint-determined wall and ceiling cavities of caves (J H. Bretz), 713

*Kansan drift of Wisconsin, wind-cut stones* (L. R. Thiesmeyer and R. E. Digman), 174
Kaolin-type minerals (S. B. Hendricks), 279
Kaolinite group of clay minerals (R. E. Grim), 233
structure (R. E. Grim), 245
Kay, George F., and Paul T. Miller. The Pleistocene gravels of Iowa. Review by Paul MacClintock, 668
Kelley, W. P. *Modern clay researches in relation to agriculture*, 307
Kern River area, regional structure of, California (L. E. Nugent, Jr.), 902
River region, California, general geology of (L. E. Nugent, Jr.), 901
*River salient, the genesis of subordinate conjugate faulting in the* (L. E. Nugent, Jr.), 900
River salient, structure of, California (L. E. Nugent, Jr.), 905
*Kilauea Volcano, ground tilt at* (H. H. Waesche), 643
Killbuck shale facies, Ohio (F. T. Holden), 49
Kincer, J. B. Cited on torrential rains in eastern United States (S. S. Visher), 98
Krumbein, W. C. Review of Factors of soil formation: a system of quantitative pedology. By Hans Jenny, 919
Review of Possible future oil provinces of the United States and Canada. A. I. Levorsen (ed.), 1004
Review of Soil physics. By L. D. Baver, 669

*Labrador, anorthosite and associated rocks about Nain* (E. P. Wheeler, 2nd), 611
Lahee, Frederic H. Field geology. Review by F. J. Pettijohn, 922
*Lake, Poohbah, Ontario, the malignites of* (C. C. Allen), 134
The last million years: a history of the Pleistocene in North America. By A. P. Coleman. Edited by George F. Kay. Review by W. C. Alden, 331
Later Wisconsin glaciation, Arizona (R. P. Sharp), 490
*Lattice structure of clay minerals and some properties of clays* (S. B. Hendricks), 276
Laverdière, J. W., and L. G. Morin. Initiation à la géologie. Review by J. D. H. Donnay, 222
Lawson, A. C. Cited on malignites of Poohbah Lake area, Ontario (C. C. Allen), 140
Cited on rocks of Poohbah Lake area, Ontario (C. C. Allen), 134
Lees, G. M. Cited on the chert beds of Palestine (H. A. Lowenstam), 827
LeRoy, L. W. Small foraminifera from the Late Tertiary of the Nederlands East Indies. Review by C. W. Sternberg, 1006
*Leverett, Frank, note by*, 1001
*Wind work accompanying or following the Iowan glaciation*, 548
Levorsen, A. I. (ed.). Possible future oil provinces of the United States and Canada. Review by W. C. Krumbein, 1004
*Lewiston, Idaho, the Asotin stage of the Snake River Canyon* (R. L. Lupher and W. C. Warren), 866
Idaho, regional geology of (R. L. Lupher and W. C. Warren), 869
*Limestone caverns, vadose and phreatic features of* (J H. Bretz), 675

Lithopolis sandstone member, Hocking Valley conglomerate, Ohio (F. T. Holden), 45
Little North Mountain, Appalachians, literature on (A. W. Giles), 963
*North Mountain of the north-central Appalachians, structure of* (A. W. Giles), 961
*Lobe, Mankato, of the Wisconsin drift plain in Iowa, swell and swale pattern of the* (C. S. Gwynne), 200
Loess in Iowa (F. Leverett), 554
Logan formation, Ohio (F. T. Holden), 53
Lookout Mountain Cave, Tennessee (J H. Bretz), 682, 696
*"Low and ball," a discussion of the use and meaning of the term* (O. F. Evans), 213
*further discussion of the term* (F. P. Shepard), 216
Lowenstam, Heinz A. *Geology of the Eastern Nazareth Mountains, Palestine*, I, 813
*Lower and Middle Mississippian stratigraphy of Ohio* (F. T. Holden), 34
jaw of Edops, Texas red beds (A. S. Romer and R. V. Witter), 949
Lowry, H. H. *Relation of the physical constitution of coal to its chemical characteristics*, 357
Ludlum, John C. *Pre-Cambrian formations at Pocatello, Idaho*, 85
Lupher, R. L., and Walter C. Warren. *The Asotin stage of the Snake River Canyon near Lewiston, Idaho*, 866
Lyndon formation, Grand Canyon, Arizona (E. T. Schenk and H. E. Wheeler), 891

MacClintock, Paul. Review of The Pleistocene gravels of Iowa. By George F. Kay and Paul T. Miller, 668
McCabe, Louis C. *Practical significance of the physical constitution of coal in coal preparation*, 406
McGill, W. M. Cited on caverns of Virginia (J H. Bretz), 795, 797, 801
MacGinitie, Harry D. A Middle Eocene flora from the Central Sierra Nevada. Review by E. P. Du Bois, 1007
Macerals and phyterals of primary coal types (G. H. Cady), 347
Maestrichtian facies, Palestine (H. A. Lowenstam), 841
Malignites, Poohbah Lake area, Ontario (C. C. Allen), 137
*the, of Poohbah Lake, Ontario* (C. C. Allen), 134
Malott, Clyde. Cited on interpretation of ceiling tubes in caves (J H. Bretz), 717
Cited on potholes in cave-stream beds (J H. Bretz), 731
Mammoth Cave, Kentucky (J H. Bretz), 687, 697
Cave region, Kentucky (J H. Bretz), 787
Cave region, relations between caverns and sinks in (J H. Bretz), 761
relations of caverns to springs in (J H. Bretz), 769
Mankato lobe, description of, in Iowa (C. S. Gwynne), 200
*lobe of the Wisconsin drift plain in Iowa, swell and swale pattern of the* (C. S. Gwynne), 200
Map, areal geologic, of Pocatello, Idaho, quadrangle (J. C. Ludlum), 87
areal, showing distribution of Lower and Middle Mississippian rocks in Ohio (F. T. Holden), 36, 37
of Carlsbad Cavern, New Mexico (J H. Bretz), 780
geologic, of Nain-Okhakh section of Labrador (E. P. Wheeler, 2nd), 615
geologic, of Snake River area, Lewiston, Idaho (R. L. Lupher and W. C. Warren), 867
geological, of the Eastern Nazareth Mountain area, Palestine (H. A. Lowenstam), 817
of Horseshoe Bay Cave, Wisconsin (J H. Bretz), 714
index, showing course of Little North Mountain, Virginia and adjacent states (A. W. Giles), 962
index, showing location of Eastern Nazareth Mountain area, Palestine (H. A. Lowenstam), 815
index, showing location of Kern River salient, California (L. E. Nugent, Jr.), 901
index, of southwestern United States (E. T. Schenk and H. E. Wheeler), 883
of involution locality, moraines, and areas covered by Kankakee torrent, Illinois (R. P. Sharp), 117
of Kilauea Crater, Hawaii National Park (H. H. Waesche), 645
location, showing Pocatello area, Idaho, and tillite in Utah (J. C. Ludlum), 86

of Luray Caverns, Virginia (J H. Bretz), 801
of Mammoth Cave Ridge (J H. Bretz), 763
of Mark Twain Cave, Hannibal, Missouri (J H. Bretz), 702
of Massanutten Caverns, Virginia (J H. Bretz), 795
of North Mountain fault and its western auxiliary, Virginia (A. W. Giles), 977
of North Mountain fault, Virginia (A. W. Giles), 978
outline, of Nain-Okhakh section of Labrador (E. P. Wheeler, 2nd), 614
photo-index, of area in Milford and Grant townships, Story County, Iowa (C. S. Gwynne), 203
showing areas of erosion in United States (S. S. Visher), 104
showing course of Little North Mountain across Frederick County, Virginia (A. W. Giles), 969
showing degree of soil erosion in United States (S. S. Visher), 105
showing extent and trends of swell and swale pattern, Mankato lobe of Wisconsin drift plain in Iowa (C. S. Gwynne), 201
showing 5 inches of rain in 8 hours (S. S. Visher), 101
showing glacial deposits on San Francisco Mountain, Arizona (R. P. Sharp), 482
showing location of facies of Cuyahoga formation, Ohio (F. T. Holden), 43
showing official records of rains (S. S. Visher), 102
showing the Paha district in Illinois (F. Leverett), 551
showing rainfalls of 2 inches in 30 minutes (S. S. Visher), 101
sketch, of drift sheets and ventifact locality in north-central Wisconsin (L. R. Thiesmeyer and R. E. Digman), 177
sketch, of Loch Ard Gorge, Victoria, Australia (George Baker), 663
sketch, of part of Shenandoah Valley, Virginia (J H. Bretz), 794
topographic, of Blue Mounds, Wisconsin (J H. Bretz), 784
topographic, of vicinity of Baker Caverns, Pennsylvania (J H. Bretz), 805
topographic, of vicinity of Crystal Cave, Pennsylvania (J H. Bretz), 803
topographic, of vicinity of Lost River Cave, Kentucky (J H. Bretz), 792
topographic, of vicinity of Luray Caverns, Virginia (J H. Bretz), 800
of Turnhole Bend and environs, Kentucky (J H. Bretz), 773

Maps, detailed, showing stratigraphy of Little North Mountain, Virginia (A. W. Giles), 970

Mark Twain and Cameron Caves, Missouri, the network of (J H. Bretz), 700
vadose alteration of phreatic passages in (J H. Bretz), 743

Marshall, C. E. *Modern conceptions of the physical constitution of coal and related research in Great Britain*, 385

*Materials, clay, modern concepts of* (R. E. Grim), 225

Mead limestone, Grand Canyon, Arizona (E. T. Schenk and H. E. Wheeler), 894

Meadville shale member, Tinkers Creek shale facies, Ohio (F. T. Holden), 52

*Meaning of the term "low and ball," a discussion of the use and* (O. F. Evans), 213

Melteigite in Poohbah Lake area, Ontario (C. C. Allen), 144

Meramec Cave, Missouri, and its stream (J H. Bretz), 694, 697
the spongework of (J H. Bretz), 698

Messina, Angelina R., and Brooks F. Ellis. A catalogue of the foraminifera. Review by Carey Croneis, 560

Middle Eocene flora, a, from the Central Sierra Nevada. By Harry D. MacGinitie. Review by E. P. Du Bois, 1007

*Lower and, Mississippian stratigraphy of Ohio* (F. T. Holden), 34

Miller, Paul T., and George F. Kay. The Pleistocene gravels of Iowa. Review by Paul MacClintock, 668

Miller, W. J. Introduction to physical geology. Review by E. P. Du Bois, 1006

*Mima mounds, the origin of the, of western Washington* (W. W. Dalquest and V. B. Scheffer), 68
mounds, Washington, initiation of (W. W. Dalquest and V. B. Scheffer), 76

mounds, Washington, origin of (W. W. Dalquest and V. B. Scheffer), 76
*Minerals, clay, lattice structure of, and some properties of clays* (S. B. Hendricks), 276
Miocene flora, a, from Shantung Province, China. By R. W. Chaney. Review by E. P. Du Bois, 223
Mississagi formation, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 11
*Mississippian, Lower and Middle, stratigraphy of Ohio* (F. T. Holden), 34
Missouri-Onondaga Cave, Missouri, and its stream (J H. Bretz), 686, 696
*Modern clay research, applications of, in ceramics* (F. H. Norton), 320
*clay researches, application of, in construction engineering* (H. F. Winterkorn), 291
*clay researches in relation to agriculture* (W. P. Kelley), 307
*concepts of clay materials* (R. E. Grim), 225
*concepts of the physical constitution of coal* (G. H. Cady), 337
Molding methods, ceramic (F. H. Norton), 324
Moneymaker, Berlen C. Cited on subriver solution cavities in Tennessee Valley (J H. Bretz), 808
Montmorillonite group, base exchange and minerals of the (S. B. Hendricks), 285
group of clay minerals (R. E. Grim), 232
structure (R. E. Grim), 238
Monzonite in Nain, Labrador, region (E. P. Wheeler, 2nd), 624
Moore, E. S. American influence in Canadian mining. Review by E. S. Bastin, 218
Morin, L. G., and J. W. Laverdière. Initiation à la géologie. Review by J. D. H. Donnay, 222
Morris Basin, Illinois (R. P. Sharp), 123
Mound prairies, description of, Washington (W. W. Dalquest and V. B. Scheffer), 69
*Mounds, the origin of the Mima, of western Washington* (W. W. Dalquest and V. B. Scheffer), 68
Mount Nelson, Tasmania (A. B. Edwards), 471
Wellington, Tasmania (A. B. Edwards), 466
*Mountain, Little North, structure of, of the north-central Appalachians* (A. W. Giles), 961
*Mountains, Eastern Nazareth, Palestine, geology of the,* I (H. W. Lowenstam), 813
*Multiple Pleistocene glaciation on San Francisco Mountain, Arizona* (R. P. Sharp), 481

Na-clay, uses of (H. F. Winterkorn), 297
*Nain, Labrador, anorthosite and associated rocks about* (E. P. Wheeler, 2nd), 611
Nature of involuted materials, northeastern Illinois (R. P. Sharp), 123
*Nazareth Mountains, Eastern, Palestine, geology of the,* I (H. A. Lowenstam), 813
Nepheline syenites in Poohbah Lake area, Ontario (C. C. Allen), 143
Newcomb, R. C. Cited on origin of Mima mounds, Washington (W. W. Dalquest and V. B. Scheffer), 83
New systematics, the. Edited by Julian Huxley. Review by Carey Croneis, 106
*Zealand, unusual olivine in basalt near Auckland* (J. A. Bartrum), 914
Noll, W. Cited on formation of clay minerals (W. P. Kelley), 315
*North American Pleistocene, progress and problems in the* (R. F. Flint), 563
*central Appalachians, structure of Little North Mountain of the* (A. W. Giles), 961
Mountain fault, continuation of, Appalachians (A. W. Giles), 978
*Mountain, Little, of the north-central Appalachians, structure of* (A. W. Giles), 961
*Northeastern Illinois, periglacial involutions in* (R. P. Sharp), 113
Norton, F. H. *Applications of modern clay research in ceramics,* 320
*Note by Frank Leverett,* 1001
Nugent, L. E., Jr. *The genesis of subordinate conjugate faulting in the Kern River salient,* 900

Occurrence of clay minerals (R. E. Grim), 258
*an, of concretions in the Pottsville of Georgia* (J. W. Sullivan), 209

Odell, N. E. The structure of the Kejser Franz Josephs Fjord region, northeast Greenland. Review by R. T. Chamberlin, 334

*Ohio, Lower and Middle Mississippian stratigraphy of* (F. T. Holden), 34

Olivine in Tasmanian dolerites (A. B. Edwards), 579
*unusual, in basalt near Auckland, New Zealand* (J. A. Bartrum), 914

*Ontario, breccia at Sudbury* (H. W. Fairbairn and G. M. Robson), 1
*the malignites of Poohbah Lake* (C. C. Allen), 134

Orangeville shale member, Tinkers Creek shale facies (F. T. Holden), 51

Origin of alkalic rocks in Poohbah Lake area, Ontario (C. C. Allen), 148
of breccia, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 29
of density currents (H. S. Bell), 515
of involutions, northeastern Illinois (R. P. Sharp), 126
of Mima mounds, Washington (W. W. Dalquest and V. B. Scheffer), 76, 82
*the, of the Mima mounds of western Washington* (W. W. Dalquest and V. B. Scheffer), 68
possible, of concretions in Pottsville of Georgia (J. W. Sullivan), 212
*the, of spits, bars, and related structures* (O. F. Evans), 846

Orthopyroxenes in Tasmanian dolerites (A. B. Edwards), 587

Orvin, A. K. Outline of the geological history of Spitsbergen. Review by C. W. Sternberg, 671

Outline of the geological history of Spitsbergen. By A. K. Orvin. Review by C. W. Sternberg, 671

Outlines of structural geology. By E. Sherbon Hills, review by R. T. Chamberlin, 923

Oxidation of constituents of coal (H. H. Lowry), 378

Paha ridges, Illinois (F. Leverett), 550

Paleobotany and the physical constitution of coal (G. H. Cady) 352

*Palestine, geology of the Eastern Nazareth Mountains,* I (H. A. Lowenstam), 813

Particle size, relation of, to base-exchange capacity of clay minerals (R. E. Grim), 252

Particles, transported, size of (H. S. Bell), 534

*Pattern, swell and swale, of the Mankato lobe of the Wisconsin drift plain in Iowa* (C. S. Gwynne), 200

Peasley limestone, Grand Canyon, Arizona (E. T. Schenk and H. E. Wheeler), 893

Pegmatite in Poohbah Lake, Ontario (C. C. Allen), 145

Pegmatitic segregations, Tasmania (A. B. Edwards), 477

Pendants in caves (J H. Bretz), 736, 741

Pennsylvania Caverns (J H. Bretz), 802

*Periglacial involutions in northeastern Illinois* (R. P. Sharp), 113

Periodicity of mountain folding in the thermal-contraction theory (J. S. De Lury), 195

Petrofabric analysis of breccia, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 25

Petrographic constituents, chemical nature of (H. H. Lowry), 373
constituents, ultimate and proximate compositions of (H. H. Lowry), 359

Petrography, effect of, on mining and preparation of coal (L. C. McCabe), 407
of the intrusive in Poohbah Lake area, Ontario (C. C. Allen), 136

Petrologic significance of the system $NaAlSi_3O_8$-$CaSiO_3$-$NaAlSiO_4$ (W. R. Foster), 167

Petrology, chemical and structural, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 17
of Tasmanian dolerites (A. B. Edwards), 460

Pettijohn, F. J. Review of Field geology. By Frederic H. Lahee, 922

Phreatic forms and patterns of caves (J H. Bretz), 698, 720
*vadose and, features of limestone caverns* (J H. Bretz), 675
and vadose histories, particular combinations and sequences of (J H. Bretz), 736

Phylogenetic position of Edops, Texas red beds (A. S. Romer and R. V. Witter), 957

*Physical constitution of coal, influence of upon its chemical, hydrogenation, and carbonization properties* (G. C. Sprunk), 411

*constitution of coal, modern conceptions of the, and related research in Great Britain* (C. E. Marshall), 385
*constitution of coal, modern concepts of* (G. H. Cady), 337
*constitution of coal, practical significance of the, in coal preparation* (L. C. McCabe), 406
*constitution of coal as related to coal description and classification* (E. C. Dapples), 437
*constitution of coal, relation of the, to its chemical characteristics* (H. H. Lowry), 357
constitution of coal, significance of (G. H. Cady), 354
properties of soils (W. P. Kelley), 312
*Physiography, a study in Appalachian* (Karl Ver Steeg), 504
Phyterals and macerals of primary coal types (G. H. Cady), 347
Pigeonites in Tasmanian dolerites (A. B. Edwards), 585
Pioche shale, Grand Canyon, Arizona (E. T. Schenk and H. E. Wheeler), 889
Plagioclase (W. R. Foster), 155
in Tasmanian dolerites (A. B. Edwards), 580
*Plain, Wisconsin drift, in Iowa, swell and swale pattern of the Mankato lobe of the* (C. S. Gwynne), 200
Plant distribution, contemporary, inference from, in interpreting postglacial climates (W. S. Cooper), 991
Plastic masses (F. H. Norton), 321
molding of ceramics (F. H. Norton), 325
properties of clay materials (R. E. Grim), 273
Plasticity (F. H. Norton), 320
Pleasant Valley member, Toboso conglomerate facies, Ohio (F. T. Holden), 48
Pleistocene gravels of Iowa, the. By George F. Kay and Paul T. Miller. Review by Paul MacClintock, 668
*multiple, glaciation, on San Francisco Mountain, Arizona* (R. P. Sharp), 481
*progress and problems in the North American* (R. F. Flint), 563
Pocatello formation, Idaho (J. C. Ludlum), 89
*Idaho, pre-Cambrian formations at* (J. C. Ludlum), 85
Pokerville Cave, Wisconsin, and its stream (J H. Bretz), 691, 696
Poohbah intrusive, Ontario, structure of (C. C. Allen), 147
Lake area, Ontario, general geology of (C. C. Allen), 134
*Lake, Ontario, the malignites of* (C. C. Allen), 134
Porphyritic alkalic syenites of Poohbah Lake area, Ontario (C. C. Allen), 142
Portsmouth shale member, Scioto Valley shale facies, Ohio (F. T. Holden), 61
Position of ventifacts, Wisconsin (L. R. Thiesmeyer and R. E. Digman), 179
Possible future oil provinces of the United States and Canada. By A. I. Levorsen (ed.). Review by W. C. Krumbein, 1004
Post, L. von. Cited on problems and working-lines in post-Arctic history of Europe (W. S. Cooper), 984
*Postglacial climates, contributions of botanical science to the knowledge of* (W. S. Cooper), 981
Potholes in caves (J H. Bretz), 731
*Pottsville of Georgia, an occurrence of concretions in the* (J. W. Sullivan), 209
*Practical significance of the physical constitution of coal in coal preparation* (L. C. McCabe), 406
*Pre-Cambrian formations at Pocatello, Idaho* (J. C. Ludlum), 85
Pretty Run sandstone facies, Ohio (F. T. Holden), 55
Primary-type coal (G. H. Cady), 342
*Problems, progress and, in the North American Pleistocene* (R. F. Flint), 563
Processing and utilization of coal (L. C. McCabe), 408
*Progress and problems in the North American Pleistocene* (R. F. Flint), 563
Properties of clays, factors controlling the (R. E. Grim), 230
*of clays, lattice structure of clay minerals and some* (S. B. Hendricks), 276
Prospect Mountain quartzite, Grand Canyon, Arizona (E. T. Schenk and H. E. Wheeler), 887
Pseudowollastonite (W. R. Foster), 156

Publications received, 672
Pyroxenes in Tasmanian dolerites (A. B. Edwards), 581
Pyroxenite in Poohbah Lake, Ontario (C. C. Allen), 145

Quartz in Tasmanian dolerites (A. B. Edwards), 591
Questionable clay minerals (R. E. Grim), 235
Quetico National Park, Ontario (C. C. Allen), 134

Raccoon shale member, Granville shale facies, Ohio (F. T. Holden), 46
*Rainfalls, regional contrasts in torrential, help to explain regional contrasts in erosion* (S. S. Visher), 96
of 10 inches in 24 hours (S. S. Visher), 100
Ramsay Lake formation, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 7
Rarden shale member, Vanceburg siltstone facies, Ohio (F. T. Holden), 62
Rate of ice retreat, Wisconsin drift plain in Iowa (C. S. Gwynne), 206
*Red beds, Edops, a primitive rhachitomous amphibian from the Texas* (A. S. Romer and R. V. Witter), 925
*Regional contrasts in torrential rainfalls help to explain regional contrasts in erosion* (S. S. Visher), 96
*Related research in Great Britain, modern conceptions of the physical constitution of coal and* (C. E. Marshall), 385
*structures, the origin of spits, bars and* (O. F. Evans), 846
Relation between glaciation and volcanic eruptions, San Francisco Mountain, Arizona (R. P. Sharp), 502
*of the physical constitution of coal to its chemical characteristics* (H. H. Lowry), 357
Relationship between adamellitic and anorthositic intrusives, Nain, Labrador (E. P. Wheeler, 2nd), 640
Report of the Subcommittee on the Ecology of Marine Organisms. Review by Walter H. Bucher, 922
*Research, related, in Great Britain, modern conceptions of the physical constitution of coal and* (C. E. Marshall), 385
*Researches, applications of modern clay, in construction engineering* (H. F. Winterkorn), 291
*modern clay, in relation to agriculture* (W. P. Kelley), 307
Results, erosional, of heavy rains (S. S. Visher), 103
*Rhachitomous amphibian, Edops, a primitive, from the Texas red beds* (A. S. Romer and R. V. Witter), 925
*River, Snake, Canyon near Lewiston, Idaho, the Asotin stage of the* (R. L. Lupher and W. C. Warren), 866
Styx conglomerate facies, Ohio (F. T. Holden), 50
Roaring River–Echo River, Mammoth Cave, Kentucky (J H. Bretz), 687, 697
Robson, G. M., and H. W. Fairbairn. *Breccia at Sudbury, Ontario*, 1
*Rock, compression creep of rubber and* (J. S. De Lury), 189
spans across cave chambers (J H. Bretz), 718
Romer, A. S., and R. V. Witter. *Edops, a primitive rhachitomous amphibian from the Texas red beds*, 925
Roy, Sharat Kumar. The Upper Ordovician fauna of Frobisher Bay, Baffin Land. Review by E. P. Du Bois, 924
*Rubber and rock, compression creep of* (J. S. De Lury), 189
Ruby Falls in Lookout Mountain Cave, Tennessee (J H. Bretz), 682, 696
Rushville shale member, Pretty Run sandstone facies, Ohio (F. T. Holden), 60

Ste Genevieve formation, Mammoth Cave, bedding-plane anastomoses in (J H. Bretz), 706
*Salient, Kern River, the genesis of subordinate conjugate faulting in the* (L. E. Nugent, Jr.), 900
*San Francisco Mountain, Arizona, multiple Pleistocene glaciation on* (R. P. Sharp), 481
*Sand stalagmites* (George Baker), 662
stalagmites, mode of occurrence, Victoria, Australia, 662
stalagmites, size and shape of (George Baker), 664
Santonian facies of Palestine (H. A. Lowenstam), 839

Sarkî Anadolu ve Mücavir Mintakalarin Tektonik Ana Hatlari: Tektonische Grundzüge Ostanatoliens und benachbarter Gebiete. By P. Arni. Review by R. T. Chamberlin, 668

Sayles, R. W. Cited on stratigraphy of Bermuda (R. F. Flint), 573

Scheffer, V. B., and W. W. Dalquest. *The origin of the Mima mounds of western Washington*, 68

Schenk, E. T., and Harry E. Wheeler. *Cambrian sequence in western Grand Canyon, Arizona*, 882

*Science, botanical, contributions of, to the knowledge of postglacial climates* (W. S. Cooper), 981

Scioto Valley shale facies, Ohio (F. T. Holden), 60

Sears, P. B. Cited on glacial and postglacial vegetation (W. S. Cooper), 984

Seawra Cave, Pennsylvania, pendants of (J H. Bretz), 736

Sections, representative, of Pleistocene deposits at Pit 6, Northern Illinois Coal Corporation (R. P. Sharp), 118
right-angle, in involution layer, northeastern Illinois (R. P. Sharp), 121

Sediments, ancient (R. E. Grim), 260
contemporaneous (R. E. Grim), 260
*density currents as agents for transporting: studies for students* (H. S. Bell), 512
transported, quantity of (H. S. Bell), 542

Senonian strata, Eastern Nazareth Mountains, Palestine (H. A. Lowenstam), 838

Separation and concentration methods of coal preparation (L. C. McCabe), 409

*Sequence, Cambrian, in western Grand Canyon, Arizona* (E. T. Schenk and H. E. Wheeler), 882

Shank, S. J. Cited on limestone and alkalic rocks, Poohbah Lake, Ontario (C. C. Allen), 150

Sharp, Robert P. *Multiple Pleistocene glaciation on San Francisco Mountain, Arizona*, 481
*Periglacial involutions in northeastern Illinois*, 113

Sharpsville sandstone member, Tinkers Creek shale facies, Ohio (F. T. Holden), 52

Shear resistance, importance of (H. F. Winterkorn), 298

Shenandoah Valley caverns (J H. Bretz), 793

Shepard, Francis P. *Further discussion of the term "low and ball,"* 216

Shonkinites in Poohbah Lake area, Ontario (C. C. Allen), 144

*Significance, practical, of the physical constitution of coal in coal preparation* (L. C. McCabe), 406

Skull of Edops, Texas red beds (A. S. Romer and R. V. Witter), 927

Small foraminifera from the Late Tertiary of the Nederlands East Indies. By L. W. LeRoy. Review by C. W. Sternberg, 1006

Smith, H. T. U. Geologic studies in southwestern Kansas. Review by C. W. Sternberg, 223

Smittle Cave, Missouri, and its stream (J H. Bretz), 679, 696

*Snake River Canyon near Lewiston, Idaho, the Asotin stage of the* (R. L. Lupher and W. C. Warren), 866

Soft anatomy, note of reconstruction of, Edops in Texas red beds (A. S. Romer and R. V. Witter), 950

Soil clay, former concepts of (W. P. Kelley), 309
dynamic problems in highway engineering (H. F. Winterkorn), 300
physics. By L. D. Baver. Review by W. C. Krumbein, 669
science and geology (W. P. Kelley), 318
stabilization, recent research in (H. F. Winterkorn), 305
systems out of reach of temperature and moisture fluctuations (H. F. Winterkorn), 294
uses in construction engineering (H. F. Winterkorn), 292

Solution without current flow in caves, specific cases of (J H. Bretz), 733

Some fossil plant types of Illinois. By Raymond E. Janssen. Review by C. W. Sternberg, 111

Spits and bars, processes involved in building of (O. F. Evans), 851
*bars, and related structures, the origin of* (O. F. Evans), 846

Splint coals, agglutinating value of bright and (G. C. Sprunk), 427

Springs, large, of Missouri (J H. Bretz), 746

Sprunk, George C. *Influence of physical constitution of coal upon its chemical, hydrogenation, and carbonization properties*, 411
and Reinhardt Thiessen. Coal paleobotany. Review by E. P. Du Bois, 1005
*Stage, the Asotin, of the Snake River Canyon near Lewiston, Idaho* (R. L. Lupher and W. C. Warren), 866
*Stalagmites, sand* (George Baker), 662
Stapes of Edops, Texas red beds (A. S. Romer and R. V. Witter), 948
Sternberg, C. W. Review of Australia. By Griffith Taylor, 224
Review of Geologic studies in southwestern Kansas. By H. T. U. Smith, 223
Review of The geology and ore deposits of northeastern New Mexico. By George T. Harley, 334
Review of Geology of the Presidential Range. By Richard P. Goldthwait, 112
Review of Outline of the geological history of Spitsbergen. By A. K. Orvin, 671
Review of Small foraminifera from the Late of Tertiary of the Nederlands East Indies. By L. W. LeRoy, 1006
Review of Some fossil plant types of Illinois. By Raymond E. Janssen, 111
Stone, R. W. Cited on Pennsylvania caves (J H. Bretz), 755, 802
*Stones, wind-cut, in Kansan drift of Wisconsin* (L. R. Thiesmeyer and R. E. Digman), 174
Stose, George. Cited on Appalachian physiography (Karl Ver Steeg), 505
Stratigraphic terminology (R. F. Flint), 569
Stratigraphy of Little North Mountain, Appalachians (A. W. Giles), 963
*Lower and Middle Mississippian, of Ohio* (F. T. Holden), 34
Stream work in caves, present-day (J H. Bretz), 679, 695
Structural evidence, detailed, evaluation of, Little North Mountain (A. W. Giles), 974
evidence, evaluation of, Little North Mountain (A. W. Giles), 966
relations of igneous rocks, Nain, Labrador (E. P. Wheeler, 2nd), 637
significance of breccia, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 15
Structure of clay minerals (R. E. Grim), 237
detailed, of Little North Mountain, Appalachians (A. W. Giles), 968
general, of Little North Mountain, Appalachians (A. W. Giles), 964
the, of the Kejser Franz Josephs Fjord region, north-east Greenland. By N. E. Odell. Review by R. T. Chamberlin, 334
*lattice, of clay minerals and some properties of clays* (S. B. Hendricks), 276
*of Little North Mountain of the north-central Appalachians* (A. W. Giles), 961
of the Poohbah intrusive, Ontario (C. C. Allen), 147
*Structures, related, the origin of spits, bars, and* (O. F. Evans), 846
*Studies for students: density currents as agents for transporting sediments* (H. S. Bell), 512
*Study in Appalachian physiography, a* (Karl Ver Steeg), 504
*Subordinate conjugate faulting in the Kern River salient, the genesis of* (L. E. Nugent, Jr.), 900
Sudbury gabbro, vein breccia in, Ontario (H. W. Fairbairn and G. M. Robson), 12
*Ontario, breccia at* (H. W. Fairbairn and G. M. Robson), 1
Sullivan, John W. *An occurrence of concretions in the Pottsville of Georgia*, 209
Sunbury formation, Ohio (F. T. Holden, 40
Superposition of silicate layers (S. B. Hendricks), 276
*Swale, swell and, pattern of the Mankato lobe of the Wisconsin drift plain in Iowa* (C. S. Gwynne), 200
*Swell and swale pattern of the Mankato lobe of the Wisconsin drift plain in Iowa* (C. S. Gwynne), 200
and swale pattern, relation of, to topography in Iowa (C. S. Gwynne), 205
Swinnerton, A. C. Review of Earth sciences. By J Harlen Bretz, 110
Cited on solutional importance of lateral flow in upper zones of water table (J H. Bretz), 745, 751, 782
Cited on variation in physiographic forms in limestone regions (J H. Bretz), 706
Syenite in Poohbah Lake area, Ontario (C. C. Allen), 145

System, the, $NaAlSi_3O_8$-$CaSiO_3$ (W. R. Foster), 160
*the, $NaAlSi_3O_8$-$CaSiO_3$-$NaAlSiO_4$* (W. R. Foster), 152, 162

Talc and mica-like minerals (S. B. Hendricks), 283
*Tasmania, differentiation of the dolerites of* (A. B. Edwards), I, 451; II, 579
Taylor, Griffith. Australia. Review by C. W. Sternberg, 224
Temperature: its measure and control in science and industry. By various authors. Review by Kenneth L. Cook, 221
*Term "low and ball," a discussion of the use and meaning of the* (O. F. Evans), 213
*"low and ball," further discussion of the* (F. P. Shepard), 216
Tertiary foraminifera, the, of Porto Rico. By J. J. Galloway and Caroline E. Hemingway. Review by E. P. Du Bois, 335
*Texas red beds, Edops, a primitive rhachitomous amphibian from the* (A. S. Romer and R. V. Witter), 925
Thermal decomposition of petrographic constituents of coal (H. H. Lowry), 375
Thiesmeyer, Lincoln R., and Ralph E. Digman. *Discussion: wind work accompanying and following glaciation*, 995
*Wind-cut stones in Kansan drift of Wisconsin*, 174
Cited on wind-cut stones in Kansan drift of Wisconsin (F. Leverett), 548
Thiessen, Reinhardt, and George Sprunk. Coal paleobotany. Review by E. P. Du Bois, 1005
Tillite series, Pocatello formation, Idaho (J. C. Ludlum), 89
Tilt, graphical representation of (H. H. Waesche), 647
*ground, at Kilauea Volcano* (H. H. Waesche), 643
and level changes, Kilauea Volcano, Hawaii (H. H. Waesche), 657
methods of measuring (H. H. Waesche), 644
Tinkers Creek shale facies, Ohio (F. T. Holden), 51
Toboso conglomerate facies, Ohio (F. T. Holden), 48
Tonalite in Nain, Labrador, region (E. P. Wheeler, 2nd), 624
Topography, buried, Wisconsin drift plain, Iowa (C. S. Gwynne), 207
of Lower Galilee, Palestine (H. A. Lowenstam), 813
*Torrential rainfalls, regional contrasts in, help to explain regional contrasts in erosion* (S. S. Visher), 96
rains, distribution of, in eastern United States (S. S. Visher), 98
*Transportation agent, wind—the dominant, within extramarginal zones to continental glaciers* (W. H. Hobbs), 556
*Transporting sediments, density currents as agents for: studies for students* (H. S. Bell), 512
Trap faults, Kern River region, California (L. E. Nugent, Jr.), 908
origin of (L. E. Nugent, Jr.), 909
Turonian formation, Eastern Nazareth Mountains, Palestine (H. A. Lowenstam), 833

Ultrabasic rocks in Nain, Labrador, region (E. P. Wheeler, 2nd), 628
*Unusual olivine in basalt near Auckland, New Zealand* (J. A. Bartrum), 914
Upper Albian–Vraconian strata, Palestine (H. A. Lowenstam), 814
the, Ordovician fauna of Frobisher Bay, Baffin Land. By Sharat Kumer Roy. Review by E. P. Du Bois, 924
*Use and meaning of the term "low and ball," a discussion of* (O. F. Evans), 213

Vadose alteration of phreatic passages in Mark Twain and Cameron caves, Missouri (J H. Bretz), 743
*and phreatic features of limestone caverns* (J H. Bretz), 675
Vanceburg siltstone facies, Ohio (F. T. Holden), 62
siltstone member, Vanceburg facies, Ohio (F. T. Holden), 62
Variables in clay that influence the molding properties (F. H. Norton), 328
Varved slate series, Pocatello formation, Idaho (J. C. Ludlum), 90
Vein breccia, Mississagi formation, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 11
breccia in Ramsay Lake formation, Sudbury, Ontario (H. W. Fairbairn and G. M. Robson), 7
breccia in Sudbury gabbro, Ontario (H. W. Fairbairn and G. M. Robson), 12
Velocity, the relationship between driving force and (H. S. Bell), 520
Ventifacts, age of, Wisconsin (L. R. Thiesmeyer and R. E. Digman), 186

description of, in Wisconsin (L. R. Thiesmeyer and R. E. Digman), 179, 180
geologic occurrence of, north-central Wisconsin (L. R. Thiesmeyer and R. E. Digman), 176
Ver Steeg, Karl. *A study in Appalachian physiography*, 504
Vinton sandstone member, Pretty Run sandstone facies, Ohio (F. T. Holden), 59
sandstone member, Scioto Valley shale facies (F. T. Holden), 62
sandstone member, Vanceburg siltstone facies, Ohio (F. T. Holden), 64
Visher, Stephen S. *Regional contrasts in torrential rainfalls help to explain regional contrasts in erosion*, 96
Vitrain (G. H. Cady), 343
(E. C. Dapples), 440
Volcanic activity, prediction of, Kilauea Volcano (H. H. Waesche), 661
*Volcano, ground tilt at Kilauea* (H. H. Waesche), 643

Waesche, Hugh H. *Ground tilt at Kilauea Volcano*, 643
Wakin, H. M. Cited on origin of Mima mounds, Washington (W. W. Dalquest and V. B. Scheffer), 82
Wall pockets in caves (J H. Bretz), 710
Ward, Freeman. Cited on the role of solution in peneplanation (J H. Bretz), 802
Warren, Walter C., and R. L. Lupher. *The Asotin stage of the Snake River Canyon near Lewiston, Idaho*, 866
Wasatch Mountains, pre-Cambrian formations of, Utah (J. C. Ludlum), 93
*Washington, the origin of the Mima mounds of western* (W. W. Dalquest and V. B. Scheffer), 68
Water-table and subwater-table streams (J H. Bretz), 745
Weathering of ventifacts, Wisconsin (L. R. Thiesmeyer and R. E. Digman), 185
Weidman, S. Cited on Arnott moraine, Wisconsin (L. R. Thiesmeyer and R. E. Digman), 176
Cited on Kansan age of Wisconsin till (L. R. Thiesmeyer and R. E. Digman), 187
*Western Grand Canyon, Arizona, Cambrian sequence in* (E. T. Schenk and H. E. Wheeler), 882
*Washington, the origin of the Mima mounds of* (W. W. Dalquest and V. B. Scheffer), 68
Wheeler, E. P., 2nd. *Anorthosite and associated rocks about Nain, Labrador*, 611
Wheeler, Harry E., and Edward T. Schenk. *Cambrian sequence in western Grand Canyon, Arizona*, 882
Williams, Howel. Crater Lake: the story of its origin. Review by R. T. Chamberlin, 221
Wilson, L. R. Cited on postglacial history of vegetation in northwestern Wisconsin (W. S. Cooper), 990
Wind Cave, South Dakota, joint-plane anastomosis of (J H. Bretz), 709
*-cut stones in Kansan drift of Wisconsin* (L. R. Thiesmeyer and R. E. Digman), 174
*—the dominant transportation agent within extramarginal zones to continental glaciers* (W. H. Hobbs), 556
*work accompanying and following glaciation: discussion* (L. R. Thiesmeyer and R. E. Digman), 995
*work accompanying or following the Iowan glaciation* (F. Leverett), 548
Winterkorn, Hans F. *Applications of modern clay researches in construction engineering*, 291
*Wisconsin drift plain in Iowa, swell and swale pattern of the Mankato lobe of the* (C. S. Gwynne), 200
snow line and southernmost limit of glaciation in the United States (R. P. Sharp), 500
*wind-cut stones in Kansan drift of* (L. R. Thiesmeyer and R. E. Digman), 174
Wissenschaftliche Ergebnisse der Niederländischen Expeditionen in den Karakorum und die Angre Angrenzenden Gebiete 1922, 1925, 1929–30, und 1935 herausgegeben von Dr. Ph. C. Visser und Jenny Visser-Hooft. By Rudolf Wyss. Review by Carl C. Branson, 109
Witter, R. V., and A. S. Romer. *Edops, a primitive rhachitomous amphibian from the Texas red beds*, 925
Wollastonite (W. R. Foster), 156
Wonder Cave, Iowa, pendants of (J H. Bretz), 738
Wyss, Rudolf. Wissenschaftliche Ergebnisse der Niederländischen Expeditionen in den Karakorum und die Angrenzenden Gebiete 1922, 1925, 1929–30, und 1935 herausgegeben von Dr. Ph. C. Visser und Jenny Visser-Hooft. Review by Carl C. Branson, 109

*In the path of war and on a main supply route of the United Nations, the Fiji Islands assume new importance, and this book gives valuable information from firsthand survey.*

# FIJI: Little India of the Pacific

By JOHN WESLEY COULTER

Written by a geographer who has lived thirteen years in the south sea islands, this small book compresses much factual data on the geography, economics, and anthropology of the Southern Pacific area with an understanding of the people and their social psychology which affect the broad problems of international relations.

This record of the growth of power of the East Indians migrating in large numbers to Fiji through the last sixty years has implications that extend beyond the borders of Fiji. The economic and political factors discussed have a vital bearing on the future of all Southern Pacific islands.

*Just published, 164 pages, 6 illustrations, $2.00*

THE UNIVERSITY OF CHICAGO PRESS

**Among the articles to appear in early numbers of *The Journal of Geology* are the following:**

*Age Relationships of Intrusive Rocks and Ore Deposits in the Red Lake Area, Ontario.* By H. C. HORWOOD and N. B. KEEVIL

*The System Albite-Anorthite-Sphene.* By A. T. PRINCE

*Climatic Character of the Interval between the Jurassic and Cretaceous in New Mexico and Arizona.* By LUNA B. LEOPOLD

*Westward Extension of the Kansas "Equus Beds."* By JOHN C. FRYE, A. BYRON LEONARD, and CLAUDE W. HIBBARD

*Bedding-Slip Movements in Fault Blocks Southwest of the Los Piños Mountains, New Mexico.* By J. T. STARK, J. J. NORTON, and M. H. STAATZ

*Glaciation of the Du Noir Valley, Fremont County, Wyoming.* By NEIL A. MINER and DAVID M. DELO

# THE JOURNAL *of* GEOGRAPHY

***Official Organ of the National Council of Geography Teachers***

*Edited by* GEORGE J. MILLER, *State Teachers College, Mankato, Minnesota*

This magazine, monthly for the school year, is devoted to the constant improvement in the teaching of geography. Every teacher of this subject will find aid both as to content and method.

## CONTENTS OF A TYPICAL ISSUE


*The Philippine Islands and Their People* - - - - - - - - - ALDEN CUTSHALL
*To Montenegro by Bus* - - - - - - - - - - - - - M. MELVINA SVEC
*Geography for the Junior Colleges* - - - - - - - - - - - CARL S. MEYER
*Aeronautics and Geography* - - - - - - - - - - - - - M. H. SHEARER
*Tracing the Footsteps of Autumn: An Educational Experiment* - - - - JOHN H. KEMLER
*Editorial Notes and News*
*Geographical Publications*


Membership in the National Council of Geography Teachers includes subscription to the Journal of Geography. Annual dues $2.50.

Subscription price $2.75 to those who are not eligible to membership in the National Council of Geography Teachers.

*Published by*

## A. J. NYSTROM & CO.

3333 ELSTON AVENUE CHICAGO, ILLINOIS

An A.A.P.G. Book (1942)

## SOURCE BEDS OF PETROLEUM

By PARKER D. TRASK and H. WHITMAN PATNODE

REPORT OF INVESTIGATION SUPPORTED JOINTLY BY THE AMERICAN PETROLEUM INSTITUTE AND THE GEOLOGICAL SURVEY OF THE UNITED STATES DEPARTMENT OF THE INTERIOR FROM 1931 TO 1941

RESULTS OF A.P.I. RESEARCH COMMITTEE NO. 4. WORK DONE UNDER ADVISORY COMMITTEE COMPOSED OF R. F. BAKER, B. B. COX, F. R. CLARK, K. C. HEALD, W. B. HEROY, L. P. GARRETT, F. H. LAHEE, A. W. McCOY, H. D. MISER R. D. REED, AND L. C. SNIDER

*"The main object of this study of lithified deposits has been to determine diagnostic criteria for recognizing source beds."*

600 pages, with bibliographies and index.
72 figures, 152 tables. 6 x 9 inches.

$4.50, POSTPAID
($3.50 to *A.A.P.G. members and associate members*)

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
Box 979, Tulsa, Oklahoma, U.S.A.

## A DESCRIPTIVE PETROGRAPHY OF THE IGNEOUS ROCKS

*By* Albert Johannsen

Volume I. INTRODUCTION, TEXTURES, CLASSIFICATIONS, AND GLOSSARY $4.50

Volume II. THE QUARTZ-BEARING ROCKS $4.50

Volume III. THE INTERMEDIATE ROCKS $4.50

Volume IV. Part I. THE FELDSPATHOID ROCKS

Part II. THE PERIDOTITES AND PEGMATITES $4.50

"Petrographers will be extremely grateful to Prof. Johannsen for assembling this valuable material which they can and will use. . . . . The writing is exact, lucid, scholarly, and . . . . is a pleasure to read and handle."—*Science Progress* (England)

The University of Chicago Press


6303 44